

Department of Medical Radiation Sciences

**Awareness and Knowledge of Radiation Protection in Interventional
Laboratory: A Comparative Study Between Australian and Saudi
Arabian Hospitals**

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**This thesis is presented for the degree of
Master of Philosophy
of
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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number SCI-44-14.

Signature:

Mohammed

Date: December 2015

Dedicated to my parents (Ali & Eidah), my wife (Basma Al Shehri) and my children
(Faris, Jumanah & Shayma)

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List of publications

There are two publications included as part of this thesis. The first one forms chapter two and was published in the journal of Current Medical Imaging Reviews. The second one comprises chapter three and has been accepted for publication in the journal of Radiation Protection Dosimetry. The list is as follows:

1. Alahmari M, and Sun Z. A systematic review of the efficiency of radiation protection training in raising awareness of medical staff working in catheterisation laboratory. Curr Med Imaging Rev. 2015; 11: 200-206. doi: 10.2174/157340561103150629120838
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National conferences

1. Alahmari M, Sun Z, Bartlett A. Radiation protection in an interventional laboratory: a comparative study of Australian and Saudi Arabian hospitals. The ARPS 2015 Conference. Canberra, Australia (6-9 October 2015). Oral presentation.

Abstract

The increased demand for interventional radiology (IR) and cardiology procedures has drawn concern because these procedures are associated with high radiation risks for both medical staff and patients. Examining staff attitudes and clinical practices is a well-known method of determining the practices performed in clinical centres and the necessity for safety improvement. By conducting a cross-sectional study in hospitals equipped with interventional machines, this study aims to investigate the attitudes and practices of medical staff engaged in interventional procedures (i.e., radiologists, cardiologists, vascular surgeons, medical imaging technicians and nurses) regarding personal radiation protection, as well as the relationship between their use of protective devices and training in radiation protection. The study is conducted in three stages: Firstly, a literature review is performed to identify the parameters that affect staff radiation dose and dose protection during interventional procedures. The second stage covers a systematic review of the efficiency of radiation protection (RP) training in minimising the radiation dose for both medical staff and patients. The third stage examines the interventional professionals' attitudes and practices by a well-designed questionnaire with regard to radiation-protection devices. This stage is conducted by surveying the samples of both targeted populations (i.e. Saudi Arabia and Australia) who are invited to complete the study questionnaires.

The systematic review focuses on the efficiency of RP training in minimising the radiation dose for both medical staff and patients. The literature search for the relevant articles was performed using five databases: Scopus, ScienceDirect, PubMed, Medline and ProQuest. The search covered English-language publications in peer-reviewed journals during the period between 2000 and 2014 reporting patient doses, staff doses, or both before and after RP training. Ten articles met the inclusion criteria and were included in the analysis. Seven of these studies showed the value of the RP training by measuring the patient dose and the fluoroscopy time (FT) pre- and post-training, whereas the remaining two of the three studies focused on the occupational doses only, and one reported patient and staff doses as well as the FT. After receiving training, a reduction was found in patient doses and FT with a mean and standard deviation of $49\% \pm 0.15$ and $12\% \pm 0.15$, respectively. Additionally, the

analysis displayed an occupational dose reduction by a mean and standard deviation of $72\% \pm 0.14$ after receiving training. This highlights the importance of RP when performing interventional radiological procedures.

The prospective study aims to achieve the main objectives of the thesis. Hard copies of an anonymous survey were distributed to all clinical departments that have interventional laboratories in the Eastern province of Saudi Arabia and metropolitan hospitals in Western Australia. In Saudi Arabia, 10 out of 12 eligible hospitals, and in Western Australia six out of eight eligible hospitals agreed to participate in the study. The questionnaire focused on operators and other healthcare professionals' practices regarding and attitudes towards radiation-protection devices. 485 copies of questionnaires were distributed to both study population (255 in Australia and 230 in Saudi Arabia). The overall response rate in Australia was 43% comprising 110 participants and 63% in Saudi Arabia comprising 147 participants. The results showed that differences exist between the countries and that training in RP has positive effects on staff attitudes and practices.

In summary, this research project shows the necessity and efficacy of RP training for providing a safer environment when utilising the fluoroscopic image-guided machines by medical staff working in the interventional laboratory. Due to the lack of RP training and reported unavailability of protective tools more often among the targeted group in Saudi Arabia than in Australia, variations exist between the two countries regarding attitudes and practices of interventional staff workers towards radiation protection tools. The trained interventional professionals in Australia (99%) tend to benefit from having an array of tools for personal RP more than the corresponding group in Saudi Arabia (68%).

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Chapter 1

Introduction and Literature Review

1.1 Background

The first percutaneous transluminal angioplasty (PTA) was performed in the 1960s by the American radiologist Charles Dotter, which is considered as the birth of interventional radiology (IR) (1). By using a guide wire and coaxial Teflon catheter, Dotter successfully dilated a superficial femoral artery (SFA) stenosis in an 82-year-old woman who refused leg amputation diagnosed due to gangrene and a painful ischaemic leg (2). Dotter and his colleague Melvin Jerkins continued to develop and refine their innovated procedure, and he reported treating 74 patients in 1966 (3). Afterwards, Alexander Margulies coined the term “interventional radiology” in 1967 and defined it as “manipulative procedures controlled and followed under fluoroscopic guidance that may be predominantly therapeutic or primarily diagnostic” (4). Interventional cardiology began 13 years after the first IR procedures. In 1976, a German cardiologist named Andreas Grüntzig successfully performed the first coronary artery balloon dilatation. The percutaneous coronary intervention (PCI) became one of the most widely performed medical procedures (5). Based on data from the Centres for Medicare and Medicaid Services in the United States, 350,134 PCIs were performed in 2009 (6). The estimated worldwide number of PCIs is over 3 million per year (5). Moreover, an interventional radiologist in a busy medical centre may perform around 800 procedures yearly (7). Although it has been acknowledged that over time and with the introduction of new IR devices and nonsurgical techniques, professionals have been faced with increasing numbers of patients, indicating that it will be the gold-standard treatment of the future (1). With this rapid revolution in interventional radiology and cardiology, they are being applied to more patients with higher risk levels (8, 9). The complexity of these procedures can also expose patients and working staff to additional radiation doses and hence require staff to wear a heavy lead apron for extended periods of time (10, 11).

1.2 Occupational health hazards of working in an interventional laboratory

In the last few decades, radiation-induced health hazards have been studied adequately (11, 12). Epidemiologic studies of atomic bomb survivors, uranium workers and patient treated with ionizing radiation indicated ionizing radiation as a risk factor in human cancer (13-15). However, working in an interventional laboratory may be associated with other potential risks that have not been defined satisfactorily (16, 17). Although a few studies have examined these non-radiation hazards, the majority were published for physicians, and very few examined all interventional team members. These occupational health problems pertain to all personnel working in these environments, including radiologists, cardiologists, vascular surgeons, technicians and nurses (12). In the Occupational Safety and Health Act of 1970, the Occupational Safety and Health Administration (OSHA) stated that every worker has the right to work in conditions that are free of known dangers (18). It is important therefore not only to focus on the radiation-related hazards but also to consider other health problems that may result from being part of an interventional team.

1.2.1 Orthopaedic complications

Knowing the nature of work in the interventional laboratory, one can predict what sorts of complications may result. Standing for long time periods and carrying a heavy lead apron while concentrating on a patient's condition and being aware of radiation are often tiring. Currently, the data strongly show that over time, orthopaedic problems are common among interventional personnel, especially those related to the spine (12). In 2004, Goldstein et al. targeted interventional cardiologists in a survey regarding orthopaedic problems related to their profession. Their data showed that nearly half of the 424 respondents indicated spinal problems and one-third reported missing work because of such issues (17). Years of work in IR were found to have a significant correlation with the incidence of spinal problems. In the same study, 25% of the participants reported other orthopaedic complications related to the ankles, hips or knees. Moreover, supporting findings appeared in a recent case control study that aimed to compare the prevalence of work-related musculoskeletal pain for workers in interventional laboratories (including physicians

and non-physicians) and those in other health professions (19). Among 1,543 respondents, 67% reported experiencing work-related pain more often than the control group. When they compared their results within the interventional job category, technicians reported incidences of musculoskeletal pain more often than nurses and physicians, at 62%, 60% and 44%, respectively. A distinct label, “interventionist’s disk disease”, has been given to the spine condition resulting from working in an interventional laboratory (20).

1.2.2 Health effects related to ionizing radiation

X-rays can be defined as short-wavelength, high-energy electromagnetic radiation produced when high-speed electrons strike a solid target (21). The energy of the x-ray photons will be transferred to the tissue atoms when passing through them, which can be called a dose of radiation. In the other words, the radiation dose received by an individual during any fluoroscopy examination is derived from the x-ray photons that entered the body and did not leave it (21). Regulators and professional bodies such as the US Food and Drug Administration (FDA) and the International Commission on Radiological Protection (ICRP) have raised concerns following incidences of deep skin ulceration and necrosis in patients who underwent coronary interventions in the 1990s (22). Radiation effects can be classified into two categories: First, carcinogenic and genetic effects, which refer to stochastic effects. Stochastic effects are related to DNA damage within single cells after receiving a radiation dose, which may lead to the development of malignancy. The probability of inducing this kind of effect is not related to the threshold and increases with dose, but there is no identifiable relationship between dose and effect (21).

The second type of radiation effects is the deterministic effect, or tissue reactions, which refers to immediate and predictable tissue changes (23). Deterministic effects, in contrast to stochastic effects, are thought to be threshold-related (i.e. cumulative-dose-dependant). Thus, the cell injury, or the reaction severity, will increase as the dose exceeds the threshold (24). The deterministic effect can be expressed as cell death following an unsuccessful attempt at cell reproduction. Some organs are more sensitive than others, and thus, the threshold differs according to the nature and condition of the exposed tissue. In most cases, radiation-induced skin injury will not manifest immediately; it is often delayed for months after the procedure (21). Most

deterministic effects appear in a form of skin injury, hair loss, radiation-induced cataracts and cardiovascular disease (11, 21).

It is reasonable to assume that for a dose of 100 mSv or lower, the risk of cancer or inheritable effects will increase with the age of the dose's recipient and differ according to tissue or organ type (25). Therefore, sensitivity to radiation tends to be greater in children and people suffering from connective tissue diseases or diabetes mellitus than in others (22, 26 and 27).

1.2.2.1 Radiation physics

The radiation dose is quantified using various parameters. First, absorbed dose, which is the amount of energy imparted per unit mass of tissue and is quantified in grays (Gy) or milligrays (mGy), is used in measuring the concentration of energy deposition within a specific tissue and provides an indication of the potential biological risk (11). The equivalent dose is another parameter used in measuring radiation dose, and it is expressed in sieverts (Sv) or millisieverts (mSv). It is the most common unit used to measure the radiation risks to staff for specific tissues. It can be defined as the dose quantity used to represent the probability of cancer induction and genetic effects (stochastic health effects). According to interventional perceptions, it is almost equal to the absorbed dose because it is the multiplication of the absorbed dose by the radiation weighting factor, which is "1" (11, 22). The tissue-weighted sum of the equivalent doses in all specified body tissues and organs can provide the mean dose for the whole body, which is known as the effective dose and quantified in Sv (22).

1.2.2.2 Dose limits

For occupational exposure, the dose limits for deterministic effects are expressed in equivalent doses, whereas the effective dose (E) is used to express the stochastic effects (28). Most countries, including the United States and the nations of the European Union, have adopted the occupational dose limits recommended by the ICRP. Although slight differences exist between these countries, they result in very similar outcomes (24). For instance, most of the States in the US follow the E limits recommended by the National Council on Radiation Protection and Measurements

(NCRP). These limits include 50 mSv as the maximum in any single year or 10 mSv multiplied by the individual's age in years for a lifetime limit (29). The nations of the European Union follow the ICRP E limit which is 20 mSv per year averaged over periods of 5 years (28).

For a working woman who has declared her pregnancy, the ICRP restricts the occupational radiation dose to the same limit as the general public. This limit includes a stipulation that the additional dose for the embryo/foetus should not exceed one mSv for the period from the reporting of the pregnancy to birth (24). The NCRP recommends a 0.5 mSv monthly equivalent dose limit for the foetus, beginning after the pregnancy being declared. A dosimeter should be worn in the inner side of protective garments and evaluated every month until delivery. A pregnant worker with an average monthly dose less than 0.1 mSv is considered to be in compliance with international recommendations (28).

In 2007, the ICRP issued new recommendations regarding radiological protection, which replaced the 1990 commission's recommendations. In the revised recommendations, the equivalent dose for the lens of the eye remains the same as in the 1990s recommendations, which is 150 mSv/year (24). However, the researchers argued that this limit is too high and that radiation-induced cataracts may be stochastic effects, rather than deterministic effects (30, 31). Therefore, in 2011, the commission released a new statement on tissue reactions and discussed recent epidemiological evidence related to tissue reaction effects for doses affecting the lens of the eye (28). In this statement, the equivalent dose for the lens of the eye is significantly reduced to 20 mSv per year, averaged over periods of 5 years, with no single year exceeding 50 mSv. Based on the new limit for the lens of the eye, the ICRP considers the threshold for this tissue to be an absorbed dose of 0.5 Gy, which could feasibly be reached within a working lifetime (32). Regarding the hands, skin and feet, the annual equivalent dose should not exceed 500 mSv (24).

1.2.2.3 Radiological and cardiological procedures and associated radiation doses

During any procedure, IR personnel should be aware that ionizing radiation can arise from three sources: the primary x-ray beam, scattered radiation that may occur when a patient's tissues are exposed to the primary beam and leakage x-rays that may be emitted from the x-ray tube in a different direction than the primary beam (33). Thus, applying techniques that reduce patient dose will result in a proportional decrease in scatter dose for the operator and generally reduce the occupational dose. In 2003, a large prospective observational study that included 2,142 IR procedures was conducted to identify procedures associated with higher radiation doses (27). This study concluded that all IR procedures may result in high radiation doses, even when performed by expert interventionists using the latest technology. Based on the nature of the lesion, its anatomic location and the complexity associated with the embolization procedures, trans-jugular intrahepatic porto-systematic shunt (TIPS) creation and renal/visceral artery stent placement, the likelihood of patient dose in these procedures is significant. Therefore, most patient skin injuries reported in the radiology literature were associated with TIPS, multiple hepatic/biliary procedures, embolization or renal angioplasty. Cardiac radiofrequency ablation and coronary angioplasty were also reported to cause skin injury (34, 35). The fluoroscopic time used to treat supraventricular and selected ventricular tachyarrhythmia in cardiac radiofrequency catheter ablation procedures ranged from 45 to 190 minutes. Table 1.1 summarises some radiological procedures and associated radiation doses.

Table 1.1: Readings of dose area product (DAP) and fluoroscopy time for procedures that may be associated with high radiation doses (27).

Procedure type	Number of cases	Period	Number of hospitals	Mean DAP* and range (Gy-cm ²)	Mean fluoroscopy time and range (min)
Biliary drainage	123 patients	3 years	7 hospitals	70.6 (3.0-386.3)	23.6 (1.1-174.4)
Nephrostomy	143 patients	3 years	7 hospitals	34.3 (0.41-418.5)	13.7 (1.3-79.4)
Pelvic vein embolization: varicocele	14 patients	3 years	7 hospitals	50.8 (7.4-190.6)	17.3 (6.4-40.5)
Pelvic arterial embolization: fibroids	90 patients	3 years	7 hospitals	298.2 (4.1-815.8)	29.4 (2.0-101.4)
TIPS creation	135 patents	3 years	7 hospitals	335.4 (14.3-1,364.4)	38.7 (3.5-153.1)
Neuro-embolization:	382 patients	3 years	7 hospitals	320.1 (29.3-243.2)	87.6 (2.6-401.3)

1.3 Radiation safety principles

The three fundamental principles of radiation safety, as recommended by the ICRP, are justification, optimisation of protection and limitation. Justification refers to the discussion between the referring physician and the interventionist to ensure that all expected procedural benefits outweigh all expected procedural risks and that no other radiation-free modalities can do the job. Optimisation can be achieved by acquiring an adequate image quality that carries the needed diagnostic information with the least amount of radiation. The principle of limitation states that all staff dealing with ionizing radiation should adhere to the dose limits recommended by the commission and other international bodies (22). The ICRP has specified the limitation principle to staff, not applying it to patient exposure, because the associated patient doses are commensurate with their medical purpose (36).

1.3.1 Strategies to minimize radiation hazards to staff during interventional fluoroscopy

All occupational radiological protection strategies are based on three main tools: time, distance and shielding (22). In an interventional laboratory, many aspects of staff radiation safety have been recommended because they have shown effective dose-reduction outcomes. These aspects include training in radiation protection (RP), planning the interventional procedure, using an appropriate protective tool, wearing a dosimeter and applying patient dose-reduction techniques.

1.3.1.1 RP training

To ensure safe operating practices, all healthcare staff dealing with ionizing radiation should have general radiation protection knowledge. Nevertheless, because interventional laboratory team members are dealing with large doses of radiation, they should be involved in a higher level of radiation protection training than other health professions (37). Training in radiation protection can increase the awareness of radiation-protection and dose-reduction techniques. Therefore, it is believed to be a basic component of a medical exposure optimisation program (38). Some recent studies have shown that providing training in RP for interventional staff will lead to dramatic patient and occupational dose reduction. In 2014, a study aimed to determine the efficiency of a 20-hour basic and advanced theoretical RP instruction on 154 interventional cardiologists. A record of DAP, fluoroscopy time (FT), the number of radiographic frames and runs for 1,540 coronary angiographic (CA) patients were taken before and after the participants underwent this training. When comparing the results before and after attending the course, a significant reduction was achieved in both mean DAP and FT, which were reduced by 48.4% and 20.8%, respectively (39). Another similar but smaller scale study was carried out using the same methodology and aimed to evaluate the effect of a 90-minute course on seven interventional cardiologists. The records of 70 CA patients after training were compared with another 70 CA patients before the training. The results showed a significant reduction in mean DAP and FT for patients after the course, these being reduced by 72% and 33%, respectively (40). Moreover, a 15-year follow-up study was designed to compare the personal dosimetry records of 17 interventional

cardiologists (nine staff cardiologists and eight interventional cardiology fellows) in three stages after starting a radiation protection program. The program included continuous RP training for staff and fellows. The real mean effective dose under the apron in the last stage of the study (1999-2004) was $1.2 \text{ mSv year}^{-1}$, which is 14% of that recorded in the first stage of the program (1989-1992) (41). In other words, 86% reduction in the occupational real mean effective dose was achieved at the last stage of the study. Authorities such as the European Commission (EC) and the Joint Commission on the Accreditation of Healthcare Organizations (JCAHO) suggested specific learning objectives and training programs ranging between 2 and 20 hours (11).

1.3.1.2 Planning the interventional procedure

Each small detail of all interventional procedures must be considered in the light of comprehensive care and expertise, especially for long and complicated procedures (42). The interventional team leader should integrate dose management via the use of radiation in an efficient and optimal way (43). Any previous procedural images, including ultrasound (US), computed tomography (CT) and magnetic resonance imaging (MRI), could define the relevant pathology and provide an anatomical outline with which to prepare for the interventional procedure (28). The proper use of pre-procedural images can also be beneficial in the selection of devices, such as catheters, balloons and stents of specific types and sizes, for angioplasty. This will ultimately shorten the procedure time and optimize the use of radiation (43).

1.3.1.3 Using the appropriate protective tools

Combining various kinds of available protective tools can result in dramatic occupational dose reduction (44). When performing procedures, wearing a lead apron and thyroid shield is considered basic safety practice for all interventional workers (28). To obtain optimal radiation protection and reduce ergonomic hazards, it is recommended to use a fitted vest/skirt apron (12). Based on standardised methods, protective aprons should be examined fluoroscopically every year and visually inspected on a daily or weekly basis for damage and defects (45).

Because radiation-induced cataracts may be a stochastic effect, anyone who regularly works in an interventional lab should utilise and properly place a ceiling-suspended transparent lead screen, especially in long cases (Fig 1.1). It can dramatically reduce doses to the neck and head (7, 44). Incidences of lens injuries have been reported in physicians and non-physician staff performing complex interventional procedures with systems that lack ceiling-suspended shields (47). Lead eyeglasses with protective side shields are an alternative tool when the ceiling-suspended shield cannot be used continuously. They can reduce the eye dose by a factor ranging from eight to ten (10, 44).

Moreover, disposable protective patient drapes have been shown to significantly reduce the dose to the operator's eyes, thyroid and hands, although their use adds some cost to the procedure. They are made from bismuth or tungsten–antimony and are placed on the patient after the operative site has been prepared and draped (47).



Figure 1.1: The appropriate position for the ceiling-suspended screen when using a tube lateral position (left image), while it is in the wrong position and thus is not protecting the operator (right image) (57)

Furthermore, the lead drapes suspended from the table are considered to be a standard component of any interventional machine installation. Whenever possible, operators should apply them because they designed to protect the lower extremities from the radiation that comes from the x-ray tube under the table (48).

The floor-based movable shield is useful in providing additional protection for the interventional professions. It is usually constructed from transparent leaded plastic, and it suits nurses and anaesthesia professionals more than other personnel (28). Leaded gloves are useful for protecting the operator's hands when they are very close to the primary beam. However, when wearing leaded gloves, automatic exposure control increases the exposure factors due to the presence of attenuating material within the primary beam. So, they do not provide protection to the operator's hands. Moreover, the forward and backscattered x-ray within the glove adds to hand exposure (33). Wearing protective gloves may also cause a false sense of security, subsequently increasing the dose (28).

1.3.1.4 Wearing Dosimeters

The level of occupational exposure should be monitored to ensure work safety. By wearing a personal dosimeter in the correct place and checking it every month, a staff member will be able to determine his or her safety status. It is recommended that interventional radiology departments set a policy requiring staff to wear two dosimeters, one under the apron and one at collar level, above the lead apron, to estimate eye dose (49). The personal dosimeter was used to provide two values of dose equivalent in soft tissue at two distance points below the surface of the body. One is $H_p(0.07)$ at 0.07 mm and $H_p(10)$ at 10 mm below the surface of the body. $H_p(0.07)$ from the collar dosimeter placed over thyroid shield or the lead apron provides a good estimate of the eye's lens dose and the dose delivered to the unshielded skin. The other dosimeter output value $H_p(10)$, from the dosimeter worn on the anterior chest inside protective garments is considered to be a good estimate of the operator's effective dose (E) (28). Some common mistakes lead to inaccurate dosimetry readings and therefore impossible estimate of the user's true occupational risk include: wearing the dosimeter inappropriately, leaving the dosimeter in a radiation environment, forgetting to wear or intentionally not to wear the dosimeter (50). A real-time radiation dosimeter may also be beneficial in terms of raising awareness among workers by visualising their doses in real time (51). Because an operator's hands may be exposed to the primary beam, it is not possible to measure their dose accurately using a body or wrist dosimeter, but a ring dosimeter may be used to monitor the hand dose (52). Pregnant workers should place a dosimeter on

the abdomen, under the lead apron, to estimate the foetal dose. This dosimeter overestimates the actual foetal dose because radiation attenuation by the mother's tissues is not considered. Radiation workers are required not to exceed the maximum permissible dose limits. When a worker reaches 0.5 mSv for the E dose, 5 mSv for the lens dose or 15 mSv in a month, the World Health Organization recommended that this employee should be contacted directly by the Radiation Protection Officer (RPO) to discuss all issues related to his or her unusual dose (53). However, it is expected that readings of interventional workers will be higher than those of other hospital staff. Copies of personnel dose reports, including the doses for the current period and the current year, should be sent to each department and individual at least once every year.

1.3.1.5 Avoiding scattered radiation area

According to the Newton's inverse square law, radiation intensity is inversely proportional to the distance from the source and becomes weaker as it spreads out farther away from the source (54). Thus, workers should stay as far as possible from the primary beam. Moreover, operators should pay attention when the x-ray tube is angulated or in lateral projections because the highest scattered radiation intensity is found on the x-ray-beam-entrance side of the patient (33). In addition, the hands must not be exposed to the x-ray source, and interventionists are recommended to use tubing extensions or a needle holder to avoid the primary beam (55). Furthermore, using an automatic injector during digital subtraction angiography and stepping out of the procedure room when feasible can also save staff from additional exposure. A recent study has shown a 50% dose reduction to the operator's hands, lead apron, and thyroid collar when using a power injector during digital subtraction angiography (DSA) (56).

1.3.1.6 Using patient dose-reduction techniques

A fundamental concept of occupational radiation safety in the interventional laboratory is that reducing unnecessary patient dose will consequently reduce the occupational dose (49). It is, therefore, beneficial to be aware of the expected radiation doses when planning or performing complex interventional procedures. The following techniques can ensure better image quality and patient dose reduction.

1.3.1.6.1 Minimizing the fluoroscopy time (FT)

Fluoroscopy should be only used to visualize moving objects or structures. Using the last-image-hold option instead of real fluoroscopy in situations such as consultation or education will minimize fluoroscopy time and radiation. The FT can be also minimized by utilizing the advantage of recording the fluoroscopy loop to review the dynamic process instead of performing a cine run (53).

1.3.1.6.2 Minimizing the number of fluoroscopic images

Imaging sequences are designed based on the examination type. For instance, the frame rate for the arteriography of the coeliac axis is one image per second for six seconds and then one image every other second for 24 seconds. Following these designed frame rates or even using the last-image-hold instead of acquiring new images will ultimately reduce both occupational and patient radiation doses (53).

1.3.1.6.3 Using good imaging-chain geometry

One of the most important measures used to reduce scattered radiation is to position the patient as far as possible from the x-ray tube and position the image receptor to be as close as possible to the patient. An approximately 25% reduction in the scattered dose has been shown when working at 80 cm from the iso-centre instead of 40 cm (57).

1.3.1.6.4 Collimation

Collimating the beam tightly to the area of interest can reduce scattered radiation and provide better image quality with a low patient dose (58). Other patient dose-reduction techniques, such as applying fluoroscopy in pulsed mode, using catheters with radiopaque tips to improve visualisation and avoiding the ant-scatter grid in children and some small adults, as well as using post image processing techniques if possible, can spare the patient from additional exposures (53).

1.3.2 Management responsibilities

Management in medical centres should provide all necessary resources that ensure that all staff receive the greatest possible protection from occupational radiation exposure (28). These resources include the following: first, the availability of adequate personal protective equipment in different sizes for anyone performing interventional procedures on a regular basis. Recently, a study aimed to investigate the availability of personal protective equipment across angiographic and interventional radiology suites in the Republic of Ireland. Forty-three percent of the responding clinical specialist radiographers felt that there were often insufficient numbers of aprons and jackets available and that there were also many issues relating to the appropriateness of the fit of these aprons and jackets (59). Moreover, radiation-monitoring instruments and services, as well as a quality assurance program, are essential component parts of a monitoring program. Occupational doses should be analysed by each department; high doses and outliers should be investigated (49). Adequate and relevant training programs should be provided for all levels of staff within the organization, including management, to develop a commitment to radiologic protection so that all concerned can contribute to the reduction and control of exposure (60).

1.4 Safety culture

Individuals' awareness of the importance of safety, their competence, motivation, attitudes, supervision and responsibility are what is meant by safety culture. It is thought that safety culture is affected and influenced by the shared corporate values of the individuals' organisational culture (61). The concept of safety culture initially began in industry and was introduced into the area of radiation by the Nuclear Agency in 1988 (61, 62). The deterministic harms reported in interventional and diagnostic radiology, along with quick development in the field, demand extra effort in management and dose and image optimization (63). To achieve this goal, the hospital should establish a safety culture within its organisation that takes into account human factors such as attitudes and behaviours (63). An essential element of adopting good practices and a safety culture in a radiology department is implementing clinical audits to cover the entire imaging-chain process, from writing

the referral to the imaging process to the radiological report (64). Some of the objectives for a clinical audit program for a radiology department, as proposed by the International Atomic Energy Agency (IAEA), are to promote the effective use of resources and assess the need for further education and training (65). Auditing can be performed by the department itself or from outside the department. However, to ensure independence, it is advisable that auditing should be undertaken by individuals from a separate department (65). The EC also states that the RPO is mainly involved in managing the technical and practical aspects of RP to ensure that a high level of competence is maintained (63). A recent study aimed to investigate the effect of sustained practice and x-ray technical changes on patient radiation dose during interventional cardiology procedures. Over a period of three years, patient- and procedure-specific cumulative skin doses were calculated and assessed retrospectively. Clinical practices and technical changes were implemented to increase staff radiation awareness, including establishing compulsory RP training for fellows, including procedure air-kerma in the report, announcing doses exceeding 6,000 mGy, establishing a standard x-ray imaging protocol and other new changes. A 40% reduction in mean cumulative skin dose was achieved by comparing the first and the last stages of the study (66).

1.5 Health professionals' attitudes toward and compliance with radiation protection

To assess the attitude towards safety within such organisations, it is worthwhile to examine the links between personal (e.g., values, beliefs and attitudes), behavioural (e.g. competencies) and organisational systems and sub-systems (61). A Korean study recommended mandating continuous RP training after finding an unacceptable level of radiation safety practice among dentists. Two hundred and sixty-seven Korean dentists participated in the study; more than the half of them held the image receptor by themselves when performing intraoral radiographic examination, collimation was utilized by less than 15% and fewer than 22% of the dental offices used a lead apron and thyroid shield to protect patients (67). Recent evidence suggests that healthcare professionals' attitudes toward the use of protective devices may differ, even though they had attended a radiation safety course. In 2013, a study surveyed the knowledge and attitudes of European urology residents with regard to

ionizing radiation. Although more than half of the respondents indicated having attended a RP program, their results showed an insufficient use of lead aprons and poor usage of other radiation protection tools (68). In the field of interventional procedures, Lynskey et al. (69) conducted a study to evaluate interventional radiologists' use and attitudes towards radiation-protection devices. A low rate of response was shown regarding the use of both leaded eyeglasses (54%) and a ceiling-suspended leaded shield (44%). Their analysis also showed that the most common two factors affecting the use of an eye-protective device were comfort and ease of use, in spite of the clear understanding that the sensitivity of the eyes to radiation is higher than that of any of other body organs. Even experienced staff can engage in inappropriate radiation safety practices, especially if a lack of training exists. Twenty-eight invasive cardiologists in Pakistan were surveyed regarding their knowledge and practice of radiation safety. A surprisingly paradoxical correlation was found: cardiologists with <10 years of experience showed better answers than those with >10 years of experience (70).

Many tools have been developed to measure safety culture; the Safety Attitudes Questionnaire (SAQ) is one of most popular tools. The SAQ was developed from the Intensive Care Unit Management Attitudes Questionnaire (ICUMAQ) over 20 years ago (71). Data collected using such tools may be used to formulate goals and strategies, assess and upgrade training programs, and perform comparisons with data from other countries (72, 73). Though medical regulations across countries have broadly presented comparable reforms aimed at higher-quality and safer healthcare, these countries are different in their strategies, periodic assessments of competence, early identification of poor performance and stages of evolution (74). Different countries may also utilise clinical practice differently (75). This constitutes the main part of this study, which will be discussed in detail in Chapter 3.

1.6 Thesis outline

Presently, research on staff radiation safety in both interventional radiology and cardiology mainly focused on the main operator, with no studies found examining the attitudes of all interventional team members, including technicians and nurses, towards RP measures. Moreover, there are no data available on the practice of radiation protection for interventional professionals in Saudi Arabia. Therefore, this study is conducted to achieve the following specific objectives:

- To investigate whether there are any significant differences between Saudi Arabia and Australia regarding the use of protection devices and the attitudes of interventional professionals (i.e., radiologists, cardiologists, vascular surgeons, medical imaging technicians and nurses) towards radiation protection?
- To determine whether there is any relationship between training in RP and the professionals' attitudes toward and uses of radiation protection devices.

We hypothesized that there exist significant differences between Saudi Arabian and Australian hospitals in terms of interventional RP and lack of RP training can affect professionals' attitudes and compliance negatively.

The thesis contains the following four chapters:

This chapter includes background on the interventional procedures, a literature review of the potential hazards of being a staff in the interventional laboratory and strategies for use in minimizing these risks.

Chapter 2 is a systematic review of the efficiency of RP training in minimising the radiation dose for both medical staff and patients. The literature search for the relevant articles was performed using five databases: Scopus, ScienceDirect, PubMed, Medline and ProQuest. The search covered English-language publications in the period between 2000 and 2014. The search was also limited to peer-reviewed articles on human subjects reporting patient doses, staff doses or both before and after RP training. This chapter shows the importance and efficacy of RP training in providing a safer work environment when utilising interventional procedures.

Chapter 3 is a prospective study that aims to achieve the thesis objectives. Hard copies of an anonymous survey were distributed to all clinical departments that have interventional laboratories in the Eastern province of Saudi Arabia and metropolitan hospitals in Western Australia. The questionnaire focused on operators and other healthcare professionals' practices regarding and attitudes towards radiation-protection devices. The results showed that differences between the countries exist and that training in RP has positive effects on staff attitudes and practices.

Chapter 4 is a summary of the research conclusion and future research directions.

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Chapter 2

A Systematic Review of the Efficiency of Radiation Protection Training in Raising Awareness of Medical Staff Working in Catheterization Laboratory

This is a pre-copyedited, author-produced PDF of an article accepted for publication in [*Current Medical Imaging Review*] following peer review. The version of record [Alahmari M, and Sun Z. A systematic review of the efficiency of radiation protection training in raising awareness of medical staff working in catheterisation laboratory. *Curr Med Imaging Rev.* 2015; 11: 200-206. doi: 10.2174/157340561103150629120838] is available at:

<http://benthamscience.com/journals/current-medical-imaging-reviews/volume/11/issue/3/page/200/>

2.1 Introduction

The use of minimally invasive, image-guided procedures in interventional radiology (IR) and cardiology has widely increased due to the benefits demonstrated by these procedures (1). However, most of these procedures are associated with a high radiation dose to the patient, even when performed by trained operators using dose-reducing technology and the latest fluoroscopic equipment (2). Additionally, regular work with radiation exposure may result in an accumulation of a personnel dose much higher than that received by non-medical staff and patients (3, 4). Because some incidences of deep skin ulceration and necrosis in patients who underwent coronary interventions were reported, concerns have been raised by regulators and professional bodies such as the US Food and Drug Administration (FDA) and the International Commission on Radiological Protection (ICRP) (5). The ICRP has also reported that a lack of awareness of potential radiation injuries, their occurrence and how to avoid them unfortunately exists among many interventionalists (6). This has underlined the importance of involving all medical staff who deal with ionizing

radiation in radiation protection (RP) training according to their role in the hospital (7, 8).

Training in RP is widely considered to be one of the basic components of medical exposure optimisation programs (9). Some recent studies have found that cardiologists who received formal RP training were more likely to be aware of radiation safety than those who did not (10, 11). However, there is a lack of systematic analysis of the effect of RP training on dose reduction when performing interventional procedures. Thus, the purpose of this review is to explore the value of RP training in minimising the radiation dose to both medical staff (i.e. team members of interventional radiology, cardiology and vascular surgery) and patients, based on a systematic review of the literature.

2.2 Materials and methods

The literature search for the relevant articles was performed using five different databases: Scopus, ScienceDirect, PubMed, Medline and ProQuest. The search covered English-language publications in the period between 2000 and 2014 (the last search was conducted in October of 2014). The keywords used for the search were ["Radiation Protection" OR "Radiation Safety" AND "Training" OR "Education" OR "Courses" AND "Interventional Radiology" OR "Cardiology" OR "Vascular Surgery"]. The search was limited to include peer-reviewed articles on human subjects reporting patient doses, staff doses or both before and after RP training. The reference lists of the selected articles were also investigated to identify any additional articles that were not found in the databases. The exclusion criteria included case study reports, review articles, animal or phantom studies and questionnaire studies. Figure 2.1 is a flow chart showing the search strategy.

This analysis was performed in accordance with the PRISMA guidelines (12). The following data were extracted from each study: authors, year of publication, number of participants, the type of participants, education type, measurement tool, patient number, mean patient dose before and after training, mean occupational dose before and after training and fluoroscopy time (FT) before and after training. Any missing data were indicated as not applicable (N/A). Data were extracted by two assessors independently, and all disagreements were resolved through consensus.

Due to differences between studies in the methods and units of measuring the patient and staff doses, all dose reductions were compared using percentage calculations. All means values \pm standard deviations were analysed and processed using Microsoft Excel 2010.

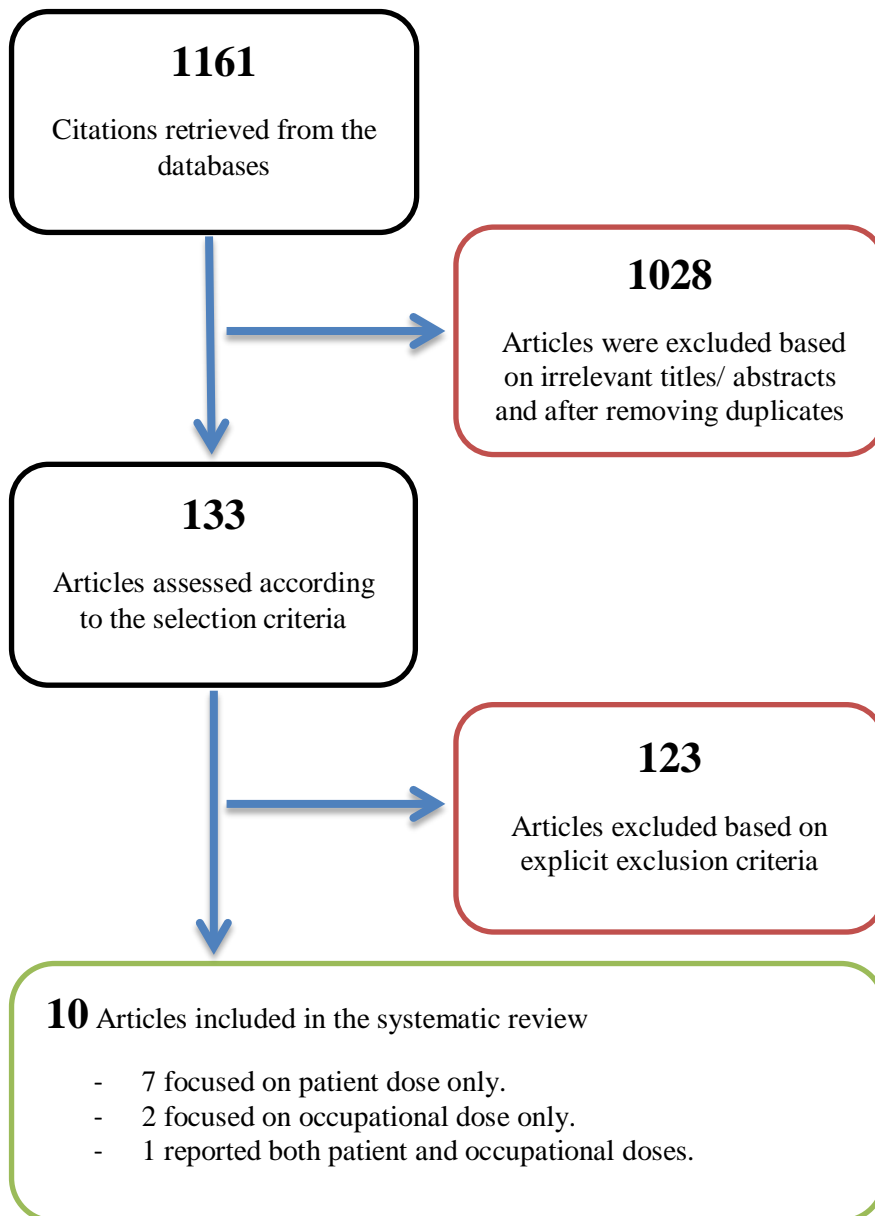


Figure 2.1: Flow chart showing the search strategy of eligible references

2.3 Results

The search process and results of selecting articles are presented in Figure 2.1. Ten articles met the inclusion criteria and were included in the study (13–22). Seven of these studies showed the value of the RP training by measuring the patient dose and the FT pre- and post-training (14–18, 20, 21), while two of the remaining three studies focused on the occupational dose only (13, 22), and the remaining one reported patient and staff doses as well as the FT (19). Three studies were reported from the same group, but with different outcomes (16–18). Thus, they were all included in the analysis.

2.3.1 Studies reporting patient dose reduction

Table 2.1 shows the study characteristics of these 10 articles. As shown in the table, the first eight studies refer to the effectiveness of the radiation safety training delivered to the participants by observing patient doses and FT. All of the participants in these eight articles were interventional cardiologists with the exception of one article (21), whose program covered both interventional radiologists and technologists because technologists are allowed to control the fluoroscopy pedal in some cases. Dose area product (DAP) and FT readings were collected prior to and after the training (in one study (13), readings of the cumulative skin dose [CSD] instead of the DAP were used). All studies reported no significant differences in patients' size number, their age, gender and body mass index (BMI) pre- and post-training. Educational events were found to vary from 90 minutes of PowerPoint workshops to 20 hours of basic and advanced theoretical courses and two days of training. A reduction in patient doses and FT after receiving training was shown in all studies by a mean and standard deviation of $49\% \pm 0.16$ and $12\% \pm 0.16$, respectively, indicating the effectiveness of implementing RP training.

Table 2.1: Study characteristics of these eligible studies (DAP-dose area product, FT-fluoroscopy time)

Authors	Year of Publication	No. and Type of Participants	Education Type	Measurement Tool	Before Attending Radiation Protection Training				After Attending Radiation Protection Training			
					No. of Patients	DAP	FT	Occupational Dose	No. of Patients	DAP	FT	Occupational Dose
Kuon et al. (18)	2014	154 Interventional cardiologists	20-h basic and advanced theoretical courses	Recording DAP, FT and number of radiographic frames and runs for CA patients before and after mini- course	1540	26.5 Gy×cm ²	159 s	N/A	1540	13.7 Gy×cm ² (48.4% reduction)	126 s (20.8% reduction)	N/A
Kuon et al. (17)	2013	7 Interventional cardiologists	90 Minute PowerPoint workshop	Recording DAP, FT and number of radiographic frames and runs for CA patients before and after 2 years from the 90 min course	70	31.4 Gy×cm ²	180	N/A	70	8.5 Gy×cm ² (72% reduction)	120 (33% reduction)	N/A
Fetterly et al. (14)	2012	27 Interventional Cardiologists and 65 fellows	Training including practical examination + x-ray system technical changes	Reporting the cumulative skin dose (CSD) for all procedures and compare between the first and last study quarters	1580	969 mGy×cm ²	7.2 min	N/A	1475	568 mGy×cm ² (40% reduction)	8.0 min (11.4% increase)	N/A
Georges et al. (15)	2009	5 Interventional cardiologists	2 days training course in radio-protection and implementing of technical recommendations.	DAP; FT and Number of runs were assessed for CA and PCI patients before and after the training program.	1072	178 Gy×cm ²	19.4 min	N/A	1128	65 Gy×cm ² (63%reduction)	16.4 min (15% reduction)	N/A

Authors	Year of Publication	No. and Type of Participants	Education Type	Measurement Tool	Before Attending Radiation Protection Training				After Attending Radiation Protection Training			
					No. of Patients	DAP	FT	Occupational Dose	No. of Patients	DAP	FT	Occupational Dose
Sheyn et al. (21)	2008	11 Interventional Radiology staff (physicians and technologists)	A detailed lecture and article were given to participants.	Recording the total FT, cumulative DAP and the use of shielding equipments 4 months before and after the educational program	432	$16.1 \pm 2 \text{ Gy} \times \text{cm}^2$	$220.1 \pm 28.4 \text{ s}$	N/A	616	$7.5 \pm 1.7 \text{ Gy} \times \text{cm}^2$ (53% reduction)	$157.2 \pm 16.6 \text{ s}$ (30% reduction)	N/A
Mavrikou et al. (20)	2008	7 Interventional Cardiologists	Training program on specific issues of radiation protection	DAP, FT, number of images and cumulative dose were obtained from the system for CA and PTCA procedures 6 months before and after the program.	982	$224.3 \text{ Gy} \times \text{cm}^2$	29.1 min	N/A	720	$174 \text{ Gy} \times \text{cm}^2$ (22% reduction)	25.1 min (13% reduction)	N/A
Kuon et al. (16)	2005	7 Interventional Cardiologists	90 Minute PowerPoint workshop	Recording DAP, FT and number of radiographic frames and runs for CA patients before and after mini course	70	$30.8 \text{ Gy} \times \text{cm}^2$	245 s	N/A	70	$19.2 \text{ Gy} \times \text{cm}^2$ (37% reduction)	266 (7% increase)	N/A
Lakkireddy et al. (19)	2009	3 Interventional Cardiologists	Implementing a comprehensive radiation safety program	Exposure doses were assessed before and after the program	21	$548 \pm 363 \text{ Gy} \times \text{cm}^2$	$74 \pm 24 \text{ min}$	$0.036 \pm 0.009 \text{ mGy}$	20	$234 \pm 120 \text{ Gy} \times \text{cm}^2$ (57% reduction)	$70 \pm 20 \text{ min}$ (5% reduction)	$0.015 \pm 0.003 \text{ mGy}$ (58% reduction)
Abatzoglou et al. (13)	2013	3 Interventional Cardiologists	Radiation protection seminar	Levels of cardiologist exposure 7 months before and 9 months after the seminar were analysed and compared.	70	N/A	N/A	N/A	70	N/A	N/A	71.6 % reduction in staff dose)
Vano et al. (22)	2006	17 Interventional Cardiologists	Continuous training for staff and fellows + continuous updating in the technical aspects.	A 15-year follow-up of personal dosimetry records (over and under their lead aprons).	Over 5000 cases per year	N/A	N/A	Real mean effective dose = 8.5 mSv year	Over 5000 cases per year	N/A	N/A	Real mean effective dose = 1.2 mSv year (86% reduction)

3.3.2 Studies reporting occupational dose reduction

The last three studies in Table 2.1 demonstrate the usefulness of the radiation safety training delivered to the participants by observing the differences in the staff doses before and after training. Interventional cardiologists were the targeted sample in all three studies. Educational events varied from a radiation protection seminar to continuous RP training and updates in the technical aspects. Because the complexity of the procedure, patient age and BMI may affect readings, all of these aspects were taken into account, and no significant differences were found. The value of the training received in these studies was displayed as a reduction in participants' doses by a mean and standard deviation of $72\% \pm 0.14$ (dose reduction ranges from 58% to 86%) (Fig 2.2).

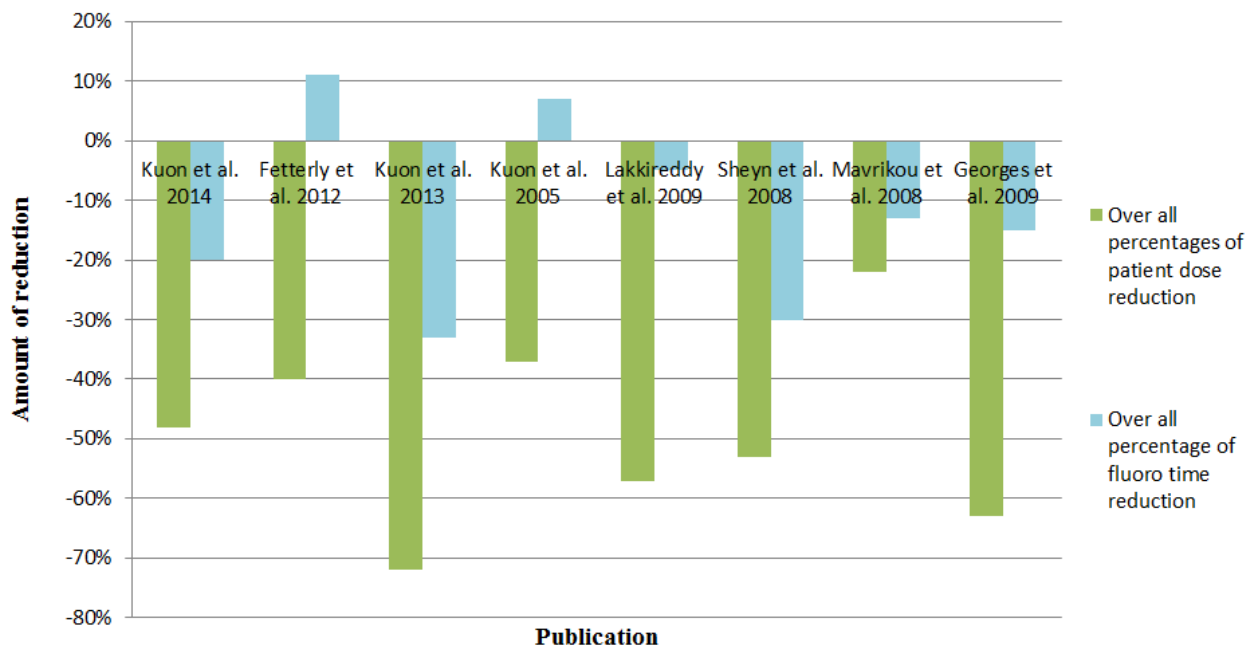


Figure 2.2: Effectiveness of dose and fluoroscopic time reduction in eight studies

2.4 Discussion

Interventionalists are very attentive to the potential complications related to each interventional procedure and do their best to avoid them. This includes justifying the requested procedure with the referring physician and explaining all benefits and possible risks before acquiring the consent of the patient (1). However, routine planning usually does not include particular aspects of radiation dose management and protection for patients and staff (23). The effects of radiation fall into two classifications: stochastic effects (including carcinogenic and genetic effects) and deterministic effects or tissue reactions, which refer to immediate and predictable changes in the tissue (24). Linet et al. stated that for a dose of 100 mSv or lower, it is reasonable to assume that the risk of cancer or heritable effects will increase according to the organ or tissue type to be irradiated or even the patient's age (25). Therefore, paediatric patients and patients with connective tissue disease or diabetes mellitus tend to be more sensitive to radiation than others (2, 26, and 27). In contrast, deterministic effects are considered to be the result of a threshold dose (i.e., cumulative dose dependant), and the severity of the reaction or cell injury will increase as the dose exceeds the threshold (28). Therefore, it is very important to be aware of the radiation dose and to implement dose reduction strategies during interventional radiology procedures because radiation exposure is a significant concern for interventionalists and patients due to increasing workloads and increasingly complex procedures over the last decade (5, 28, and 29).

In 2006, IR procedures were estimated to be the third largest source of ionizing radiation, representing 14% of all medical exposure in the United States (29). Thus, to assure optimal patient and personnel safety, it is recommended that each catheterisation laboratory should have their own radiation safety and fluoroscopic training policies based on appropriate sources (30, 31). Secondly, the institution that provides X-ray fluoroscopic services should employ a credentialing process to give authority before operating the equipment. This includes a compulsory knowledge threshold that is required to fulfil the role of physicians performing fluoroscopically guided procedures (30). Recommendations on the curriculum can be provided by some international organisations such as ICRP, the European Commission (EC) and the World Health Organisation (WHO) (8). A range of between two and 20 training

hours is suggested by authorities such as the EC and the Joint Commission on the Accreditation of Healthcare Organization (JCAHO). The education style could involve didactic courses, computer-based instruction or self-study, and the acquired knowledge should be tested with by a certifying exam (30, 31). This review further supports the idea that significant dose reduction was achieved after receiving radiation protection training.

There are some limitations in this analysis. First, studies included in the analysis were from 2000 and onwards because we focused on the RP training practice over the last 15 years, although there were early publications emphasising the importance of RP training. The low number of eligible references was another limitation, especially those focusing on staff doses. Additionally, missing or unreported values in some articles minimised the characteristics of the extracted data. Some of the included studies have a small number of participants, adding another limitation to the study. Moreover, this analysis only looked at the overall dose reduction due to the training programme and did not assess how these doses were measured. This review was also limited to studies published in English, which may have contributed to a biased opinion in the study findings. Finally, all references were found to focus on the main operator rather than those of the entire team including technicians and nurses. Consequently, the need to generalise these findings to the entire group of catheterisation laboratory workers presents a limitation. Therefore, it may be desirable to include technicians and nurses in future studies because they are also exposed to the potential radiation hazards.

In conclusion, this systematic review shows that radiation protection training leads to a significant reduction in dose to medical staff and patients. Regulatory and healthcare authorities should play an important role in maintaining safety when interventional radiology procedures need to be utilised.

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Chapter 3

Radiation Protection in an Interventional Laboratory: A Comparative Study of Australian and Saudi Arabian Hospitals

This is a pre-copyedited, author-produced PDF of an article accepted for publication in [*Radiat Prot Dosimetry*] following peer review. The version of record [Alahmari M, Sun Z, Bartlett A. Radiation protection in an interventional laboratory: a comparative study of Australian and Saudi Arabian hospitals. *Radiat Prot Dosim*. Published online February 1, 2016 doi:10.1093/rpd/ncv547. Is available online at: <http://rpd.oxfordjournals.org/content/early/2016/02/01/rpd.ncv547.full.pdf>

3.1 Introduction

The number of minimally invasive, fluoroscopy-guided procedures has significantly increased because of its benefits over traditional invasive approaches (1, 2). However, both interventional radiologists and cardiologists are exposed to the highest levels of ionizing radiation in the medical field while imaging in multiple series with real-time x-rays (3). Despite the fact that there is no increased cancer risk among medical radiation workers who are exposed to the current levels of radiation doses by complying with safety regulations, it is important to be aware of the evidence that no level of radiation exposure is free of associated risks (4, 5). The stochastic effect, or radiation-induced malignancy, is a result of DNA damage that may develop after receiving any dose of ionizing radiation, since there is no identifiable threshold relationship between the dose and effect (6). Further, neglecting safety guidelines can result in radiation exposure exceeding the recommended threshold levels, causing deterministic ionizing radiation effects. Skin injury, hair loss and cataract formation are examples of deterministic effects (7, 8). However, some recent studies suggested that the lens of eyes is more sensitive to radiation than what is previously believed and the radiation-induced cataract formation could be stochastic effect without any threshold. These studies confirmed incidences of lens opacities at doses lower than 0.5 Gy among A-bomb survivors, astronauts, and staff in interventional laboratories (9, 10, 11).

Recent evidence suggests that healthcare professionals' attitudes and use of protective devices may differ even though they are aware of radiation safety procedures. In 2013, a study surveying the knowledge and the attitude of European urology residents with regard to ionizing radiation showed insufficient use of lead aprons and very poor usage of other radiation protection tools, even though more than half of respondents have attended a radiation protection (RP) program (12). Another study conducted by Lynskey et al. (13) evaluated the interventional radiologists' use and attitudes towards radiation protective devices. Their data analysis showed that in spite of the clear understanding of the sensitivity of the eyes to radiation being higher than any other body organs, a low response was shown regarding the use of leaded eyeglasses (54%) and a ceiling-suspended leaded shield (44%). The two most common factors affecting the use of the eye protective shield were comfort and ease of use. Although it is unclear why interventional radiology (IR) personnel are compromising protection for comfort, it may be due to a lack of strong regulations requiring their use or an inadequate understanding of the benefits of these devices (13). Presently, research on staff's radiation safety in both interventional radiology and cardiology focused mainly on the main operator with no studies examining attitudes and uses of the entire interventional team members, including technicians and nurses towards RP measures.

Although medical regulations across countries have broadly shown similar reforms towards better quality and safer healthcare, these countries are different in their strategies, periodic assessments of competence, early identifications of poor performance as well as the stages of evolution (14). In addition, a recent research suggests that different countries utilize clinical departments differently (15). Currently, there are no data available on the practice of RP for interventional professionals in Saudi Arabia. The primary objective of the present study was to identify any significant differences between Saudi Arabia and Australia regarding the use of protection devices and the attitudes of interventional professionals (i.e., radiologists, cardiologists, vascular surgeons, medical imaging technicians, and nurses) towards RP. The secondary objective was to determine any relationship between training in RP and the professionals' attitudes and use of protection devices. We hypothesized that there exist significant differences between Saudi Arabian and

Australian hospitals in terms of interventional RP and lack of RP training can affect professionals' attitudes and compliance negatively.

3.2 Materials and Methods

3.2.1 Questionnaire design

This study was designed by taking a reference from the questionnaire developed by Lynskey et al. (13) (see reference for details of the study design), which comprised of eight comprehensive questions. However, the survey used in their study targeted mainly the interventional radiologists. While in the current study, this was modified to make some changes including deleting two questions from the list (Q5 and Q6) and reformatting and transferring Q8 to a demographic variable. These questions are “Q5, How often are the other personnel in the room protected with following devices (residents and fellows)”, “Q6, How often are support personnel in the room protected with the following devices? (Nurses, technicians, anesthetists)” and “Q8, How many years have you been in practice since becoming an attending physician?” Additionally, labels of the protective devices were reordered and reduced from nine to eight by merging two devices together into one label. Some choices were also added to Q3 in order to change it from an open-ended to a close-ended format. Specific demographical variables (i.e. age, gender, occupation, experience, and training level) were also added to the survey. The amended survey questionnaire was then presented to four radiologists for content and face validation, with two of them being academic staff and the other two clinical interventional consultants. This study was approved by Institutional Review Boards of Curtin University and other relevant clinical centers.

3.2.2 Participants

After obtaining sites' participation approval and by using a cross-sectional design, hard copies of the anonymous survey were distributed to clinical departments that have interventional laboratories in the Eastern province of Saudi Arabia and metropolitan hospitals in Perth, Western Australia, Australia. In Saudi Arabia, 10 out of 12 eligible hospitals, and in Western Australia six out of eight eligible hospitals agreed to participate in the study. Eligible participating hospitals included private,

public and military hospitals. Furthermore, interventional professionals including radiologists, cardiologists, vascular surgeons, medical imaging technicians and nurses must work regularly in these clinical practices. Temporary workers in interventional procedures (e.g., anesthetists, physicians and nurses from other departments) were excluded from the study. The study was focused on the specific population of healthcare professional delivering an interventional service to patients; thus, the convenience sampling technique was followed. A reminder was given one week before collecting the questionnaires. 485 copies of questionnaires were distributed to both study population (255 in Australia and 230 in Saudi Arabia). The questionnaire comprised seven general questions and five questions with four being comprehensive questions focusing on operators and other healthcare professionals' use and attitudes towards RP devices (see Appendix 1).

3.2.3 Statistical analysis

Using the IBM Statistical Package for Social Science (SPSS) software, version 22.0, two-way frequency tabulations were tested for contingency by the Chi-squared test. Categorical variables were presented as frequencies or percentages. In terms of hypothesis testing, $p < 0.05$ was considered to be statistically significant.

3.3 Results

3.3.1 Percentage of response rates in both countries

The overall response rate was 43% (n=110) in Australia (20% interventionists, 29% technologists and 51% nurses) and 64% (n=147) in Saudi Arabia (21% interventionists, 31% technologists and 48% nurses). 99% of the Australian participants and 68% of the Saudi participants had received training in RP.

3.3.2 Comparison of the frequency of usage of protective devices

3.3.2.1 Saudi participants versus Australian participants

The results showed no significant differences between the Saudi and Australian participants in terms of usage of lead aprons, thyroid shields, sterile lead equivalent

patient mounted drapes and radiation-attenuating sterile surgical gloves ($p=0.118$, 0.566 , 0.129 and 0.190 , respectively). However, the percentages of participants who never used leaded eyeglasses were higher among the Australian participants than the Saudi participants (64% and 46% respectively, $p < 0.001$). The Australian participants tended to utilize the ceiling-suspended transparent screen more often than the Saudi participants did, at rates of 57% and 47%, respectively ($p < 0.001$). Additionally, 66% of the Australian participants used the lead drape suspended from the table in every case, while only 41% of Saudi participants used it in every case ($p < 0.001$). More than half of the Saudi participants (63%) never used the floor-based movable lead shield, compared with 25% of the Australian participants ($p < 0.001$). Figure 3.1 and Table 3.1 summarize the differences in these four factors between the two countries.

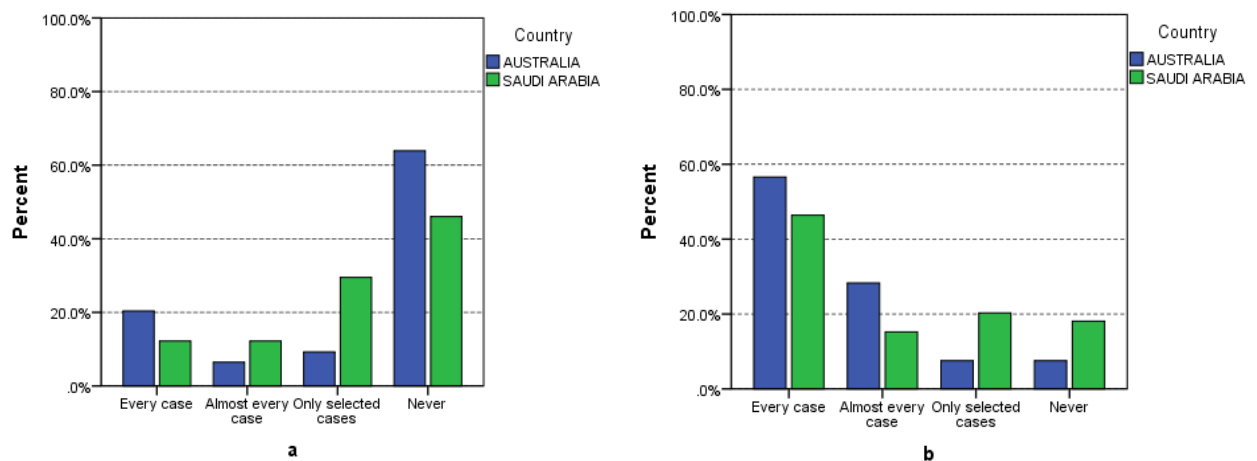


Figure 3.1: Comparison between Saudi and Australian participants' usage frequency of leaded eyeglasses (a) and ceiling suspended transparent screens (b).

Table 3.1: Significant differences in protective device usage between the Saudi and Australian participants

Protective devices	Country (Count + percentage within country)								<i>p</i> Value
	Australia				Saudi Arabia				
	Every case	Almost every case	Only selected cases	Never	Every case	Almost every case	Only selected cases	Never	
Leaded eyeglasses	22 20%	7 7%	10 9%	69 74%	17 12%	17 12%	41 30%	64 46%	0.000 <i>p</i> < .001
Ceiling-suspended screen	60 57%	30 28%	8 8%	8 7%	64 47%	21 15%	28 20%	25 18%	0.000 <i>p</i> < .001
Lead drape suspended from table	69 66%	19 18%	7 7%	10 9%	53 41%	22 17%	17 13%	37 29%	0.000 <i>p</i> < .001
Floor-based movable shield	28 28%	13 13%	35 34%	25 25%	16 13%	9 7%	21 17%	77 63%	0.000 <i>p</i> < .001

3.3.2.2 Trained versus untrained staff

There was highly significant difference between the staff who received training in RP and those who did not. The percentages of participants who never used leaded eyeglasses were higher among the untrained staff than the trained staff (67% and 51%, respectively; $p < 0.01$). The ceiling-suspended transparent screen was used in every case by 55% of the trained respondents, compared to 33% of the untrained workers ($p < 0.01$). The trained professionals also demonstrated more frequent usage of the lead drape suspended from the table in every case compared to the untrained staff (57% versus 29%, respectively; $p < 0.001$). Finally, 75% of the untrained respondents never utilised the floor-based movable lead shield, compared to 40% of the trained staff ($p < 0.001$). Table 3.2 shows the differences in these four factors between trained and untrained staff.

Table 3.2: Significant differences in protective device usage between staff trained in RP and staff untrained in RP presented as frequencies, percentages and P values

Protective device	Trained staff				Untrained staff				p Value
	Every case	Almost every case	Only selected cases	Never	Every case	Almost every case	Only selected cases	Never	
Leaded eyeglasses	38 19%	20 10%	41 20%	103 51%	1 2%	4 9%	10 22%	30 67%	0.011 $p < .01$
Ceiling-suspended screen	109 55%	43 22%	26 13%	20 10%	15 33%	8 17%	10 22%	13 28%	0.003 $p < .01$
Lead drape suspended from table	109 57%	34 18%	17 9%	30 16%	13 29%	7 16%	7 16%	17 39%	0.001 $p < .001$
Floor-based movable shield	42 23%	18 10%	52 28%	74 40%	2 5%	4 10%	4 10%	28 75%	0.000 $p < .001$

3.3.2.3 Comparison of differences within job categories

Figure 3.2(a) shows that higher percentage of nurses had never used the leaded eyeglasses compared to the technologists and doctors (68%, 49%, and 24%, respectively, $p < 0.001$). Percentage of nurses and technologists who never used the radiation-attenuating sterile surgical gloves was higher than the doctors (98%, 97%, and 79%, respectively, $p < 0.001$). Regarding the sterile lead equivalent patient-mounted drape, 90% of the technologists never used it, compared to 79% of the nurses and 68% of the doctors ($p < 0.01$). Higher percentage of nurses used ceiling-suspended transparent screen in every case compared to the technologists and doctors (53%, 51% and 44%, respectively, $p < 0.05$), (Figure 3.2, b). More than half of doctors (66%) and technologists (54%) used the lead drape suspended from the table in every case, whereas the percentage was lower among the nurses (45%, $p < 0.05$) (Figure 3.2 c). Finally, 50% of nurses, 43% of technologists, and 37% of doctors never used the floor-based movable shield ($p < 0.05$).

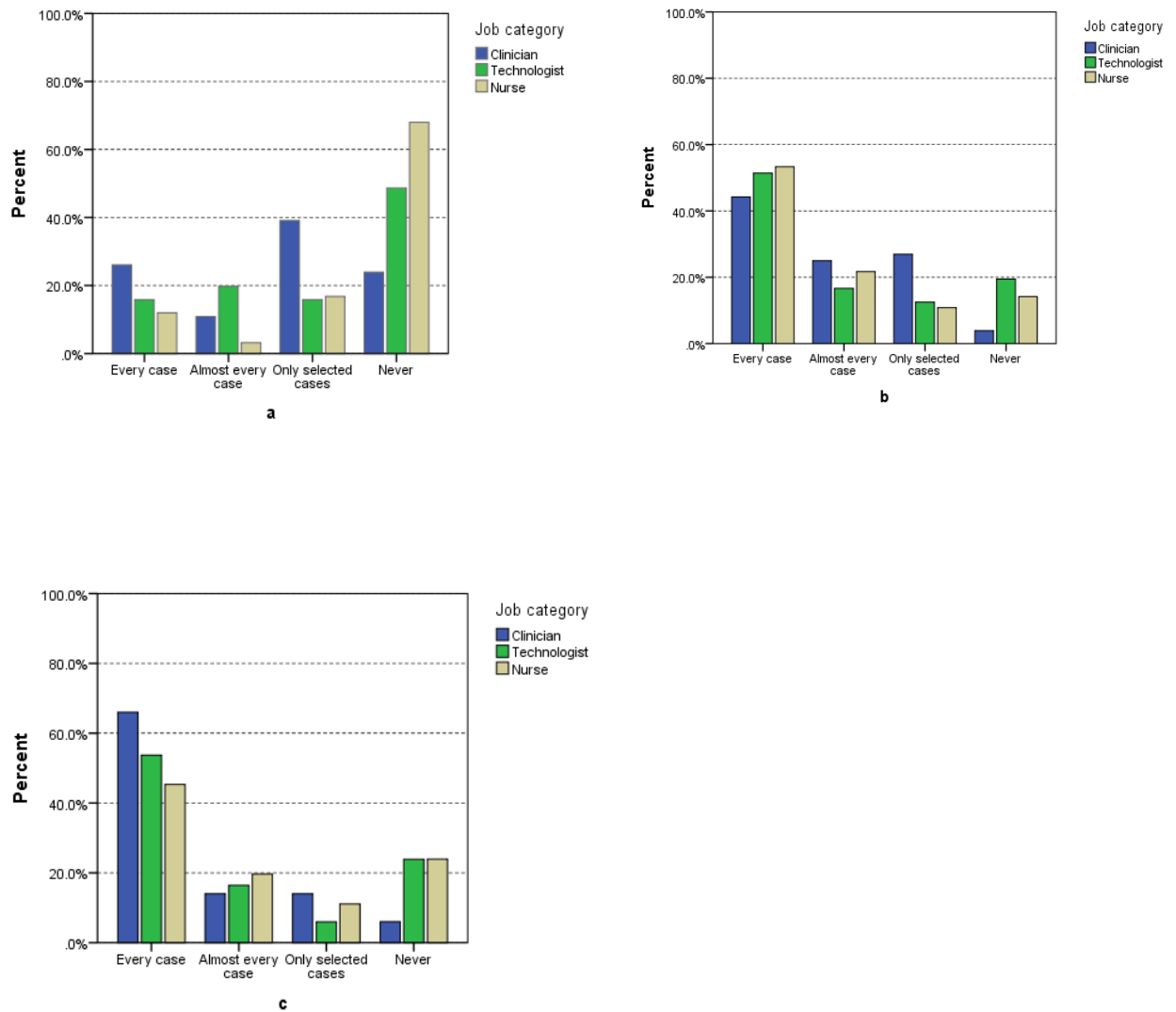


Figure 3.2: Comparison of the usage frequency by job type of (a) leaded eyeglasses, (b) ceiling suspended screen, and (c) lead drape suspended from the table.

3.3.3 Comparison of factors affecting each protective device

3.3.3.1 Saudi participants versus Australian participants

Table 3.3 shows the most common factors that can affect the use of protective devices in Australia are as follows: lack of availability for eyewear, patient mounted drape and radiation-attenuation surgical gloves; ease of use for ceiling suspended

shield, the table hanging shield and floor based shield; and comfort for lead apron and thyroid shield. In contrast, in Saudi Arabia, the most common factor was the lack of availability of eyewear, table-hanging shield, floor based shield, patient mounted drape, and radiation-attenuation surgical gloves. The second common factor was comfort with respect to the use of lead apron, thyroid shield and ceiling suspended shield.

Table 3.3: The most frequently selected factors affecting the usage of each device based on country

Safety device	Australia (110 respondents)		Saudi Arabia (147 respondents)	
	Usage factor	Frequency	Usage factor	Frequency
Lead apron	Comfort	31 (28%)	Comfort	77 (52%)
Thyroid shield	Comfort	26 (24%)	Comfort	91 (62%)
Leaded glasses	Not available	38 (34%)	Not available	56 (38%)
Ceiling-suspended screen	Ease of use	27 (24%)	Comfort	47 (32%)
Lead drape suspended from table	Ease of use	18 (16%)	Not available	50 (34%)
Floor-based movable shield	Ease of use	26 (24%)	Not available	82 (56%)
Sterile lead equiv. patient-mounted drape	Not available	64 (58%)	Not available	96 (65%)
Radiation-attenuating Sterile surgical gloves	Not available	68 (62%)	Not available	94 (64%)

3.3.3.2 Trained versus untrained staff

Table 3.4 displays the differences between the most common factors given by the trained and untrained staff regarding their use of each protective device. The trained staff chose comfort as the reason for not using the lead apron and the thyroid shield. The ease of use was chosen for ceiling-suspended screen. Lack of availability was the dominant selected factor for the usage of the following devices: leaded eyeglasses, lead drapes suspended from table, floor-based movable shield, sterile lead equivalent patient-mounted drape, and radiation attenuating sterile surgical gloves. By contrast, untrained workers chose comfort and lack of availability more often than the other factors. Comfort was selected for the lead apron, thyroid shield and the ceiling suspended screen. However, lack of availability was selected most often for the following: leaded eyeglasses, lead drapes suspended from table, floor-based movable shield, sterile lead equivalent patient-mounted drape, and radiation attenuating sterile surgical gloves.

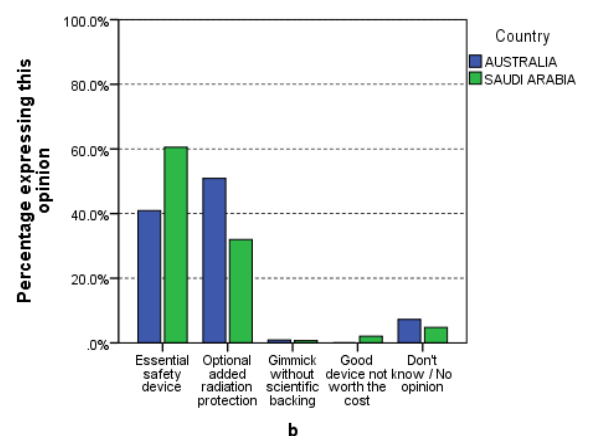
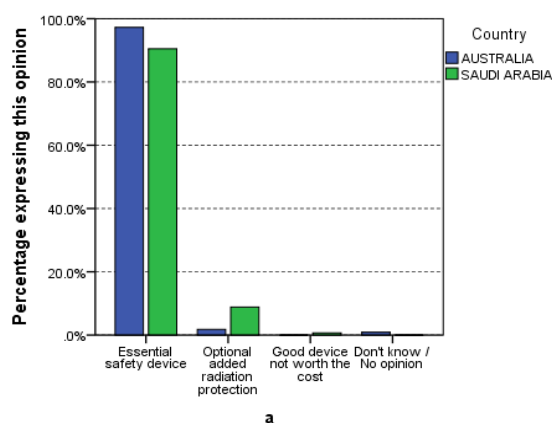
Table 3.4: The most frequently selected factors affecting the usage of each device based on training

Safety device	Trained staff (209 respondents)		Untrained staff (48 respondents)	
	Usage factor	Frequency	Usage factor	Frequency
Lead apron	Comfort	81 (39%)	Comfort	27 (56%)
Thyroid shield	Comfort	85 (41%)	Comfort	32 (67%)
Leaded eyeglasses	Not available	67 (32%)	Not available	27 (56%)
Ceiling-suspended screen	Ease of use	57 (27%)	Comfort	18 (37%)
Lead drape suspended from table	Not available	39 (19%)	Not available	19 (39%)
Floor-based movable shield	Not available	64 (31%)	Not available	37 (77%)
Sterile lead equiv. patient-mounted drape	Not available	125 (60%)	Not available	35 (73%)
Radiation-attenuating Sterile surgical gloves	Not available	125 (60%)	Not available	37 (77%)

3.3.4 Comparison of respondents' attitudes towards the protective devices

3.3.4.1 Australian participants versus Saudi participants

Both countries showed similar attitudes towards using the lead apron and the floor-based movable lead shield. However, as shown in Figures 3.3(a) - 4(f), differences existed between the two countries with regard to other devices: 97% of the Australian participants answered that the thyroid shield was an essential device, whereas the percentage was slightly lower among the Saudi participants (90%, $p < 0.05$). More than half of the Saudi respondents (60%) responded by stating that the leaded eyeglasses were essential, while 51% of the Australian participants provided answers as optional ($p < 0.01$). More Australians than Saudis indicated that the ceiling-suspended screen was an essential safety tool, at 86% and 67%, respectively ($p < 0.01$). Similarly, 82% of the Australian participants and 57% of the Saudi participants said that the lead drape suspended from the table was an essential device ($p < 0.001$). In addition, more Australian participants than Saudi participants had no opinion regarding the sterile lead equivalent patient-mounted drapes (43% and 20% respectively; $p < 0.001$) and the radiation-attenuating sterile surgical gloves (38% and 18% respectively; $p < 0.001$).



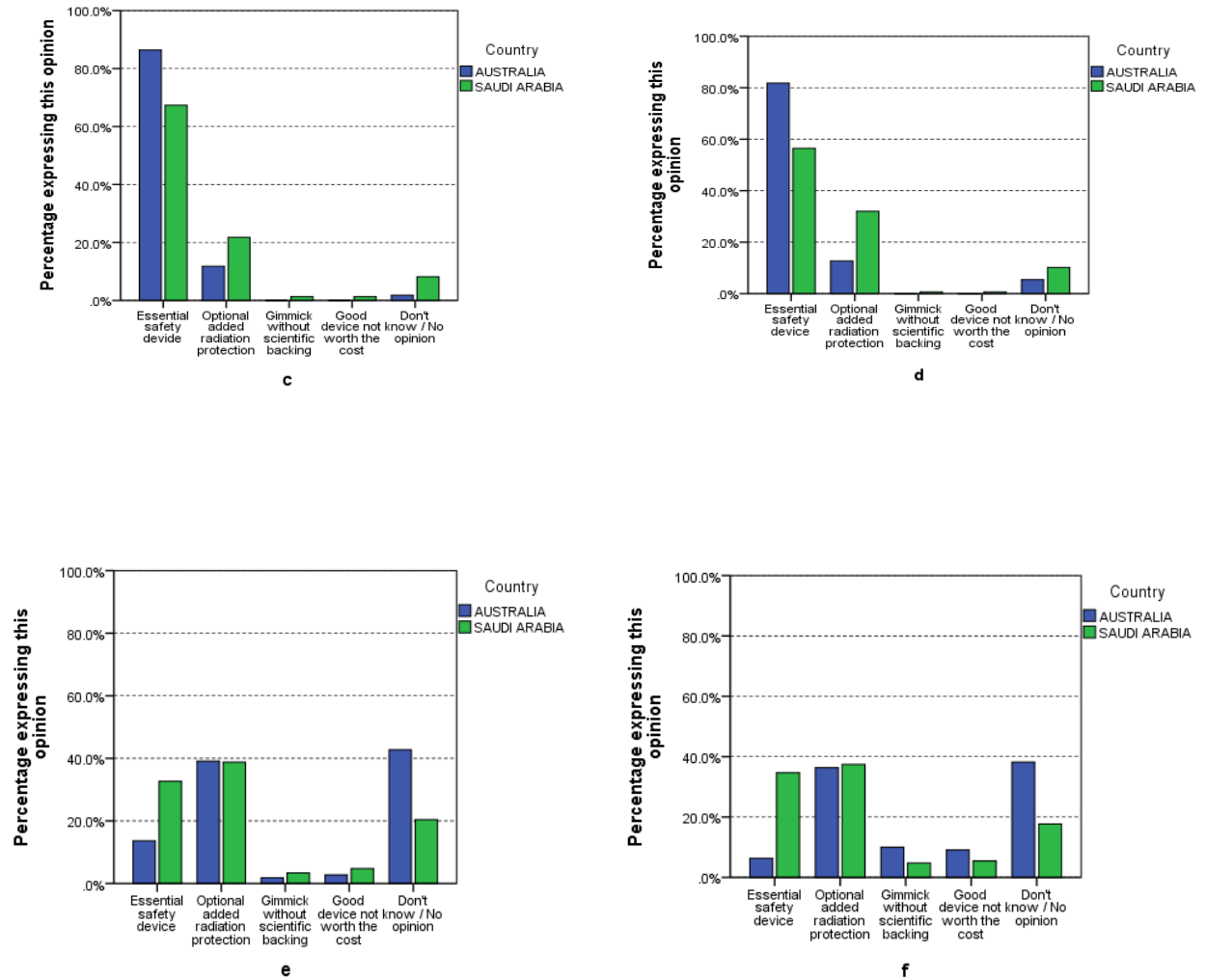


Figure 3.3: Comparisons of the Saudi and Australian respondents' opinions of the following protective devices: (a) thyroid shield, (b) leaded eyeglasses, (c) ceiling suspended screen, (d) lead drape suspended from table, (e) lead equivalent patient mounted

3.3.4.2 Trained versus untrained staff

There were no significant differences between the opinions of the trained and untrained staff regarding six RP devices: the lead apron, thyroid shield, lead eyeglass, ceiling-suspended screen, lead drapes suspended from table, and the sterile lead equivalent patient-mounted drape. As shown in Figure 3.4(a), the majority of trained staff (52%) said these were optional devices, whereas the untrained staff (50%) said these were essential safety devices ($p < 0.01$). Additionally, a higher

percentage of trained staff (40%) believed that the radiation-attenuating sterile surgical gloves were an optional device, while 46% of the untrained workers responded that they were an essential device ($p < 0.001$, see Figure 3.4, b)

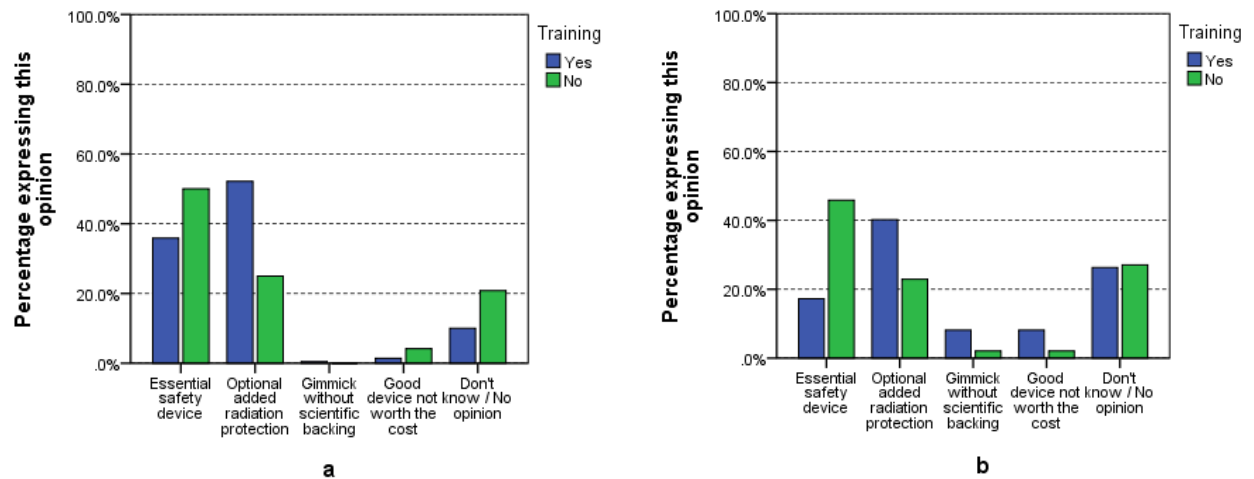


Figure 3.4: Comparison of the trained and untrained groups' opinions of (a) the floor based movable shield and (b) the leaded sterile gloves.

3.3.4.3 Comparison within job categories

The analysis showed similar attitudes among the doctors, technologists, and nurses regarding the use of five of the eight protective devices: the lead apron, thyroid shield, lead eyeglasses, ceiling-suspended screen, and lead drapes suspended from table. With regard to the floor-based movable lead shield, 71% of doctors and 49% of technologists said that it was an optional device, while 48% of the nurses said that it was an essential safety device ($p < 0.001$). With regard to the sterile lead equivalent patient-mounted drape, the doctors' attitudes varied between optional (45%) and no opinion (41%), the nurses' opinions ranged between essential (31%) and optional (36%) and higher percentage of the technologists' responses stated that it was an optional device (39%) ($p < 0.01$). Finally, the responses within all professional categories indicated that the radiation-attenuating sterile gloves were an optional device (38% doctors, 42% technologists, and 34% nurses, $p < 0.001$).

3.3.5 Comparison of respondents' attitudes towards body parts

3.3.5.1 Saudi participants versus Australian participants

The Australian participants ranked the importance of the risk to body parts as follows: thyroid and gonads (60%) ranked first followed by eyes (44%), bone marrow (43%), skin (15%) and hands (14%). The Saudi participants ranked the importance of the risk to body parts as follows: 80% of participants chose the thyroid as the most important, followed by the gonads (78%), bone marrow (65%), eyes (62%), skin (41%) and hands (31%).

3.3.5.2 Trained versus untrained staff

The employees trained in RP showed the highest percentage of concern about the risk of radiation to body parts as follows: thyroid (69%), gonads (67%), eyes (53%), bone marrow (51%), skin (25%) and hands (21%). The untrained staff rated the risk of radiation to body parts as follows: thyroid and gonads (88%), bone marrow (75%), eyes (63%), skin (50%) and hands (31%).

3.3.5.3 Comparison within job categories

The body parts of most concern to the doctors were as follows: thyroid (64%), gonads (58%), eyes (53%), bone marrow (40%), skin (26%) and hands (24%). The technologists' concerns for the risk of radiation to body parts were as follows: gonads (77%), thyroid (70%), eyes (54%), bone marrow (47%) and hands (17%). The nurses' concerns for the risk of radiation to body parts were as follows: thyroid (76%), gonads (72%), bone marrow (67%), eyes (55%), skin (35%) and hands (28%).

3.4 Discussion

This study has significant findings which could provide guidance for interventionalists when performing these procedures in the operating room, with the aim of implementing appropriate protocols for ensuring the best practice while minimising radiation exposure. Findings of this study are being discussed with

clinicians to explore the opportunity of incorporating these suggestions to the clinical practice. The key findings of this study are summarized as follows. First, 99% of Australian participants were involved in RP training versus 68% of participants from Saudi Arabia. Second, a lack of availability was the most commonly cited factor as the barrier in using five protective tools in Saudi Arabia and three protective tools in Australia. Third, the Australian participants placed greater importance on protecting the entire head including the eyes than the Saudi participants. Fourth, trained participants were more positive about the effectiveness of the protective tools and showed better compliance accordingly than untrained participants.

RP training is considered by all international bodies as a key component for reducing medical radiation doses, while maintaining optimum imaging quality (16). Recent studies have shown that cardiologists formally trained in RP are more aware of radiation safety than those who are untrained (17, 18). A recent systematic review showed that RP training can efficiently raise the awareness of medical staff working in a catheterization laboratory and reduce their exposure to radiation doses (19). The International Commission on Radiological Protection (ICRP) indicates that interventional procedures are mainly operator dependent with slight variances in techniques and roles existing among centers. Therefore, the ICRP underlined the importance of involving all individuals who perform interventional procedures in RP training. The commission further specified special recommendations for professionals working in the interventional laboratory: (1) the training should be higher in level than that designed for diagnostic radiology; (2) whenever new techniques or equipment are implemented, additional specific training is desirable; (3) a quality assurance program for IR facilities should be combined with RP training and dose control assessment techniques (20).

3.4.1 Lead apron and thyroid shield

This study found that lead aprons and thyroid shields were widely used by both the Australian and the Saudi participants. These two devices are universally known as standard practice for any profession in an interventional laboratory including physicians, technologists, and nurses (13, 21). Worldwide regulations necessitate the use of a lead apron with at least 0.5 mm lead-equivalent, which can attenuate more

than 90% of scattered radiation (22). Although the best protection practice is to apply a thyroid shield at all times, it is typically an optional protective device recommended for personnel exceeding 4 mSv of monthly collar radiation monitor readings (23). The risk of radiation-induced thyroid cancer is highly dependent on age, and thus, using a thyroid collar becomes less critical for workers over 40 years of age (24, 25). The majority of participants from both populations (97% in Australia and 90% in Saudi Arabia) failed to answer correctly when they chose the option that the thyroid shield is an essential safety device. Most of the participants were unclear about the purpose of thyroid shield, although majority of them indicated they had received RP training, and this needs to be clarified. However, our study did not show whether they received the higher level of RP training recommended by the ICRP or attended a general level of RP events. Even after receiving training, they might have been confused as to the best safety practice in the interventional laboratory and the correct thought about the thyroid shield.

The dominant factor that affects the use of the lead apron and the thyroid shield in both countries is comfort. Klein et al. (9) stated that standing for long hours and carrying a heavy lead apron is usually uncomfortable. An appropriately fitted apron is essential for providing optimum RP and reducing ergonomic problems for operators and staff who regularly work in the interventional laboratory (21). Currently, the highest selling protective apron is made of lightweight lead composite or lead free material (antimony, barium, tin and tungsten) which weighs only 30% of an equivalent thickness of lead and provides the same attenuation level (22). Many operators prefer the configuration of the vest/skirt design, as it distributes the apron's weight between the wearer's shoulders and hips (22, 26).

In general, most participants from both countries displayed the best practice when using the lead apron and the thyroid shield in every case. Their attitudes towards the lead apron also represented a good awareness. However, thoughts about the necessity of the thyroid shield should be corrected, except for the 9% of Saudi participants and 2% of Australians who demonstrated a better understanding.

3.4.2 Lead eyeglasses, ceiling suspended transparent screen and sterile lead equivalent patient mounted drape

In 2007, the ICRP published a revised radiation protection document based on the 1990 commission's recommendations. The revised recommendations specified 150 mSv as the annual equivalent dose limit for the eye's lens which is the same as in the 1990s recommendations. However, this limit underwent revision by the task group of the ICRP, as many researchers have argued that the formation of radiation-induced cataracts may occur after exposure to a single dose of radiation (stochastic effect) rather than the threshold limit (7, 27, 28). Hence, a new statement has been released by the commission in 2011 reducing the equivalent dose for the lens of the eye to 20 mSv per year, averaged over periods of 5 years, with no single year exceeding 50 mSv (29). A busy interventional specialist performing around 800 procedures per year may reach the lens dose limit (30). It is thus preferable to employ the ceiling suspended shield in all cases, as it provides protection for the entire head, not only the eyes. However, in cases where this shield interferes with the interventionist's ability to perform the procedure, leaded eyeglasses with side shields should be worn (6).

Our study showed differences between the Saudi and Australian participants' use of lead eyeglasses and ceiling suspended screens. In every case, the Australian respondents (20%) used lead eyeglasses more than the Saudi respondents (12%). In addition, the Australian participants indicated using the ceiling-suspended transparent screen more often than the Saudi participants at rates of 57% versus 47% in every case, respectively, and 28% versus 15% in almost every case, respectively. According to the data analysis in this study, it is shown that the Australian participants use eye and head protection more than the Saudi Arabian participants. There are several possible explanations for these results: First, it could be due to the lack of RP training among Saudi participants, as about one third did not receive RP training compared with 99% of trained workers in Australia. This explanation is supported by the very significant difference found in our results between trained and untrained staff (Table 2). Lack of training could therefore lead to an insufficient understanding of the different optional protection devices.

Another possible explanation is that individuals' thoughts towards protective tools may reflect negatively or positively on his or her compliance. This interpretation is clearly illustrated by the data derived from the Australian participants. More professionals considered the ceiling suspended screen an essential device (82%) than those who considered the leaded eyeglasses essential (41%) (Figure 3.3). Subsequently, the Australian respondents utilized the ceiling suspended screen (57%) much more than the leaded eyeglasses (20%) in every case. Similarly, regarding the sterile lead equivalent patient mounted drape in both countries, more professionals either had no opinion on it or considered it an optional device (Figure 3.3); this contemplation could be caused by a lack of availability, as indicated by more than half of both countries (Table 3.3), and a belief that few will benefit from its value (Table 3.1). However, despite more than 60% of Saudi participants acknowledging the sensitivity of eyes to the hazards of radiation and agreeing with the necessity for leaded eyeglasses and ceiling suspended screens, their use of these devices is much more limited than that of the Australian participants. The limited usage of the leaded eyeglasses among Saudi participants could be due to the lack of availability indicated by around one-third of them. Therefore, unavailability or limited accessibility (available but not enough) could be a valid justification. However, it is still unclear why about 30% of Saudi respondents cited comfort affecting the use of such important device like the ceiling suspended screen. This may reflect a lack of good habits reinforced by the regulations mandating their use, as suggested by Lynskey et al. (13).

An additional possible explanation as to why opinions are varied about the above protective devices may be due to different hospitals having different policies and different staff having different roles. Our study supports this justification, as there are highly significant differences within job classifications (doctors, technologists and nurses), regardless of the country origin. A higher percentage of nurses (68%) had never used the leaded eyeglasses compared to the technologists (49%) and doctors (24%). In addition, the nurses (53%) displayed higher usages of the ceiling-suspended transparent screen in every case compared to the technologists (51%) and doctors (44%). Regarding the sterile lead equivalent patient-mounted drape, 90% of the technologists had never used it, compared to 79% of the nurses and 68% of the doctors.

Although scattered radiation decreases in proportion to the inverse squared distance from the irradiated area, combining various types of shielding leads to dramatic dose reduction (21). This guarantee is either for the main operator or for assistance staff. However, not all laboratory suites contain all protective methods, and it is even possible to find different tools in different suites within the same unit. Therefore, an appropriate understanding of how to deploy the available shielding methods for maximal effective protection is critical (31). A recent study declared that using the transparent lead glass screen can only achieve a 19-fold dose reduction to the eye (32). Moreover, several phantom studies (30, 33, 34) have revealed that doses at the lens are undetectable when using a combination of lead eyeglasses and a lead suspended glass screen, and a 5- to 25-fold dose reduction occurs when utilizing leaded eyeglasses alone (30). Similarly, in a small prospective controlled trial, the lead equivalent patient-mounted drape has been shown to considerably decrease radiation dose to interventionists by 29-fold for the hands, 26-fold for the thyroid and 12-fold for the eyes (35). At the same time, the radiation dose to assistants is reduced to a negligible level without an additional dose to the patient (13, 21). Another study showed a 23% total body dose reduction to the main operator with a bismuth-barium disposable drape (36).

In summary, the findings of this study suggest that the opinions towards lead eyeglasses and the ceiling suspended screen and acts according to these views are better among the Australian participants than the Saudi participants. Employing the available protective tools effectively is fundamental in radiation safety. It is essential that all interventional team members have access to a range of protective devices according to their role.

3.4.3 Lead drape suspended from the table

Presently, lead curtains suspended from the table alongside the ceiling-suspended lead screen are considered the standard shields supplied with fluoroscopy systems for use in interventional laboratories (6). One of the conclusions drawn from the European research project, Optimisation of RP of Medical staff (ORAMED), is that the leg doses are reduced by 4.5 to 6.8 times when applying the table shield (37). However, a steep oblique or lateral position of the C-arm tube could prevent its

availability (21, 22). The uses and attitudes towards this important protective device from the Australian and the Saudi participants were highly different, thus adding another key finding to our results. Among the Australian participants, 82% considered the table suspended lead drape an essential device, resulting in 62% of them using it in every case; whereas, 57% of Saudi respondents considered it an essential device, resulting in only 41% using it in every case. The most obvious finding to emerge from the analysis is that comparing the responses between job categories showed that more doctors utilize this particular tool than technologists and nurses. Therefore, this may explain why utilizing the lead drape suspended from the table is limited in Saudi Arabia. In other words, different centers have different policies and each professional will act upon his role in the laboratory. The factors governing the lack of use of this protective tool were lack of availability in Saudi Arabia (34%) and ease of use in Australia (16%). Notably, trained professionals demonstrated much greater usage of this device compared to untrained staff. However, 39% of the untrained staff indicated unavailability as a limitation to their usage. As almost all the untrained staff were from Saudi Arabia, except one from Australia, it is likely that the Saudi participants had inadequate awareness of such an important device to benefit from its availability. However, our study did not intend to explore further reasons behind the shortages in supply in both countries. Therefore, lack of availability could also be a logical reason for the poor usage in Saudi Arabia.

3.4.4 Floor-based movable lead shield

Floor-based rolling and stationary shields constructed of transparent leaded plastic are useful for providing additional shielding for operators and staff. They are designed particularly to suit duties of nurses and anesthesia personnel (6). The Australian respondents seemingly benefit from this device according to their role, as their responses are almost equally distributed between every case, almost every case, only selected cases and never (Table 3.1). The main barrier affecting their use of the floor-based movable shield is its ease of use. The Saudi participants cited lack of availability as the dominant factor (cited by 56%) preventing them from taking advantage of these shields, as 63% of them had never used one. Both countries had correct opinions towards this device, as greater percentages understood it is optional.

One of the interesting finding of this study is that training had an effect on the respondents' thoughts: 77% of the untrained staff indicated lack of availability as the main factor leading to their poor usage of these shields. However, the majority of them were unsure of its necessity (50% believed it to be an essential device and 21% had no opinion).

3.4.5 Radiation attenuating sterile surgical gloves

Compared with other body parts, interventionists' hands may be exposed to the direct beam resulting in high doses of radiation, especially during complicated procedures. Sterile protective surgical gloves are now available with attenuation levels ranging from 15%–30% (22). Nevertheless, two factors may contradict the usefulness of this protective tool: first, applying any shield in the direct beam will increase the dose and x-ray technique factors, and second, wearing protective gloves may cause a false sense of security, subsequently increasing the dose (38). Therefore, it is not recommended to use the leaded gloves when the operator's hands are placed in the primary radiation beam, but they may be of benefit if the hands are close to the beam. One expected finding is that doctors indicated their usage of protective gloves more often than technologists and nurses. This is normal, as most of the literature discusses using the protective gloves when placing the operator's hands into or close to the primary beam (21, 22).

Our study showed no differences in the usage of the sterile leaded gloves between the two countries or the trained and untrained groups. Lack of availability was cited as the main factor for the lack of use by most participants in both the populations. However, the Australian participants were slightly more cautious than the Saudi participants regarding the necessity of leaded surgical gloves, providing answers of "no opinion" (38%) and "optional device" (36%) compared to the Saudis' opinions of "essential device" (35%) and "optional device" (37%) (Figure 3.3). Notably, differences in attitudes also existed between the trained and untrained groups. The trained staff showed a better understanding than the untrained staff; however, this could be due to the fact that the Saudi participants' were influenced by the presence of more untrained respondents among them.

3.4.6 Respondents concerns towards body parts

Dose limits for occupational exposure adopted by most countries in the world and recommended by the ICRP are based on the sensitivity of the body part to the radiation (stochastic and deterministic effects) (21). Dose limits for deterministic effects are expressed in equivalent doses, whereas the effective dose (E) is used to express the stochastic effects. Calculating the effective dose can indicate the overall effect of radiation on the exposed organs and tissues. To calculate the effective dose, the equivalent dose to any particular organ or tissue is multiplied by a tissue weighting factor (8).

Sufficient epidemiological information suggests that thyroid, gonads, and bone marrow are considered among the tissues and organs with high sensitivity to the tumorigenic effects of radiation (stochastic effects). The tissue weighting factors for these tissues are 0.04, 0.08 and 0.12 respectively (7). Logically, the effective dose limit for these body parts should be low (20 mSv per year, averaged over defined periods of five years and not exceeding 50 mSv in any one year). Moreover, as mentioned earlier, the eye's lens maybe classified as stochastic and thus 20 mSv should not be exceeded in the annual dose limit. By contrast, because the tissue weighting factor (0.01) and the sensitivity of the skin and hands to the radiation is lower than the other body organs, they are classified to be deterministic and their equivalent dose limits are 500 mSv for the skin and hands (7).

One of the objectives of this study is to determine the differences between workers at the catheterization laboratory from both countries regarding the use of the protective tools based on their attitudes towards them. Concerns regarding the risk of radiation-induced health problems were rated similarly by all the different groups of our study's respondents. The thyroid and gonads were of the greatest concern followed by bone marrow and eyes, while the skin and hands were of least concern. Consequently, the lead apron and thyroid shield were used more often than the other protective tools. These two devices are known to be the fundamental tools to protect the thyroid glands, gonads and bone marrow, which are the top rated organs concerning our study's participants. As the hands were of least concern for our respondents, the least utilized protective tools were the lead equivalent patient mounted drape and the leaded surgical gloves. However, attention should be paid to

the protection of the eyes, especially in Saudi Arabia. Although 63% of the Saudi participants ranked the eyes to be the most important body part compared to 44% in Australia, eye protection is seemingly better in Australia than in Saudi Arabia, as mentioned earlier.

3.5 Limitations

The generalizability of this study's results is subject to certain limitations. First, the small sample size, especially of the interventionists and technologists, did not allow for a comparison between each job category from the two countries. Further, the limited responses from doctors did not allow us to common on the working experiences by physicians. Second, the study did not intend to distinguish between practices such as public from private, public or military institutions, this data were analyzed collectively; therefore, it is unknown whether the practices are enforced by the policies at each of the selected hospitals. The study is also limited by the lack of information on the hospitals' accreditations, and this could further explain the variations reported between the Australian and Saudi Arabian respondents. Simplifying the answer by reducing the number of options in some questions could have ensured higher responses.

3.6 Conclusion

In conclusion, this study indicates that the trained interventional professionals in Australia (99%) tend to benefit from having an array of tools for personal RP more than the corresponding group in Saudi Arabia (68%). The different responses from the Saudi and Australian participants might be related to differences in clinical practice management between the two countries. Although the model for clinical practicum in Australia does not always need to be emulated, much can be learned from the comparative results of the data in this study. Overall, this study strengthens the idea that RP training must be considered for all medical practitioners according to their role in dealing with the ionizing radiation. Future studies could assess the reasons why some of the protective devices are not readily available for use.

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Chapter 4

Conclusions and Future Directions

4.1 Conclusions

In this thesis, we have investigated the attitudes of interventional professionals including interventionists, technologists and nurses towards radiation protection (RP) devices used in both Saudi Arabian and Australian hospitals. The staff' usages of these protective tools were also examined to determine if there are any significant differences between the two populations.

A systematic review of the efficiency of RP training programs in raising awareness of staff working in the interventional laboratory has demonstrated the usefulness of administrating these programs in order to provide safer working environment. The analysis of the literature also showed that the RP training has an effect on maintaining staff and patient doses in compliance with the principle of as low as reasonably achievable ("ALARA principle") when utilising x-ray fluoroscopy. The results of the systematic review supported our hypothesis to some extent, which is lack of RP training can negatively affect professionals' attitudes and compliance.

The prospective study was designed and conducted to address the two objectives of this project. These objectives are as follows: first, to investigate whether there are any significant differences between Saudi Arabia and Australia regarding the use of protection devices and the attitudes of interventional professionals (i.e., radiologists, cardiologists, vascular surgeons, medical imaging technicians and nurses) towards radiation protection; second, to determine if there is any relationship between training in RP and the professionals' attitudes toward the use of radiation protection devices. Our results showed that variations exist between Saudi Arabian and Australian hospitals regarding attitudes and practices of interventional laboratory workers towards radiation protection tools. A relationship between RP training and staff attitudes and use of RP devices has also been confirmed. The research findings are summarised as follows:

- The trained interventional professionals in Australia (99%) tend to benefit from having an array of tools for personal RP more than the corresponding

group in Saudi Arabia (68%). A lack of availability was the most commonly cited factor as the barrier in using five protective tools in Saudi Arabia and three protective tools in Australia.

- The Australian participants placed greater importance on protecting the entire head including the eyes than the Saudi participants due to the standard of awareness of radiation practitioners in Australia as to radiation protection in general.
- Trained participants were more positive about the effectiveness of the protective tools and showed better compliance accordingly than untrained participants.
- Although the model for clinical practice in Australia does not always need to be emulated, much can be learned from the comparative results of the data in this study.

4.2 Future directions

This study strengthens the idea that RP training must be considered for all medical practitioners according to their role in dealing with the ionizing radiation. The comparative data in this study also reflect the importance of regulators' role in providing and maintaining safety within organisations. Therefore, the following suggestions may be beneficial for the future research:

- Due to limited response from doctors reported in this study, further studies should focus on encouraging more responses from specialists, in particular cardiologists and vascular surgeons as these specialists are getting more involved in interventional radiological procedures.
- A qualitative method (case study) is recommended for further research to enhance the current study. A case study may be conducted by structured interviews with healthcare providers and senior health managers to evaluate their current perception in regards to the radiation safety culture in their organisations. This will assist the effective implementation of relevant guidelines for radiation protection to healthcare professionals working in an interventional laboratory.

- Further studies are also necessary to examine the relationship between the hospital size and the accreditation status as this may shed some light on the rationale behind lack of RP training among interventional personnel, and answer the questions as to why some of the protective devices are not readily available for use in some hospitals.
- For future studies, it may be worthwhile to consider the effect of gender type, work experience and age groups on the staff safety compliance and attitudes.

Appendix 1: the survey questionnaire of attitudes and uses of interventional laboratory workers towards RP devices

Awareness and knowledge of radiation protection in interventional radiological procedures: A comparative study between Australian and Saudi Arabian hospitals



Section A: General background information.

Mark one answer by crossing in the circle:

- 1- What is your gender?
 - ☐ Male
 - ☐ Female
- 2- What is your age?
 - ☐ From 21 to 30 years
 - ☐ From 31 to 40 years
 - ☐ From 41 to 50 years
 - ☐ Over 51 years
- 3- What is your job title in the interventional laboratory/imaging suite?
 - ☐ Radiologist
 - ☐ Cardiologist
 - ☐ Vascular surgeon
 - ☐ Technologist
 - ☐ Nurse
- 4- How long have you worked in the interventional laboratory/imaging suite?
 - ☐ Less than one year
 - ☐ 1 to 5 years
 - ☐ 6 to 10 years
 - ☐ More than 10 years
- 5- Have you received any training in radiation protection?
 - ☐ Yes
 - ☐ No
- 6- If yes, how frequently have you been involved in radiation protection training?
 - ☐ Only once, during my time as a student.
 - ☐ Only once, prior to starting my job
 - ☐ Every year
 - ☐ Other.....
- 7- If no, do you wish to have training in radiation protection?
 - ☐ Yes
 - ☐ No, Why?.....

Section B: Answer the following specific questions by crossing in the circle:

1- How often do you use the following radiation safety?

	Every case	Almost every case	Only selected cases	Never	Not applicable	Not available
Lead or lead equivalent wearable apron	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thyroid shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Leaded eye glasses	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ceiling suspended transparent screen +/- lead shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lead drape Suspended from the table	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Floor based movable lead shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sterile lead equivalent patient mounted drape	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Radiation attenuating sterile surgical gloves	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2- Which of the following factors affects your use of the following radiation safety devices? Tick as many as applicable.

	Comfort	Musculoskeletal/ Spine problems	Concern for contami- nation issues	Ease of Use	Device not available	Not enough scientific evidence	Not worried about radiation	Not needed with other barriers in place	Fear of penalty	N/A: I use as often as possible
Lead or lead equivalent wearable apron	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thyroid shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Leaded eye Glasses	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ceiling suspended transparent screen +/- Lead shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lead drape Suspended from the table	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Floor based movable lead shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sterile lead equivalent patient mounted drape	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Radiation attenuating sterile surgical gloves	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**3- If you checked "Fear of penalty" for any of the above, please answer the following question.
Fear of penalty is affecting my use of the protective device because:**

- ☐ It is a part of the departmental policy.
- ☐ It is regularly checked by the department of the radiation safety.
- ☐ Others (please specify)

4- What is your opinion of the following devices?

	Essential safety device	Optional added radiation protection	Gimmick without scientific backing	Good device not worth the cost	Don't know/ No opinion
Lead or lead equivalent wearable apron	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thyroid shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Leaded eye glasses	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ceiling suspended transparent screen +/- lead shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lead drape Suspended from the table	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Floor based movable lead shield	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sterile lead equivalent patient mounted drape	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Radiation attenuating sterile surgical gloves	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

5- In your opinion, please rate the following by the body part you are most concerned about regarding the risk of radiation-induced health problems in your clinical practice.

	Most important	Very important	Important	Somewhat important	Least important	No opinion/ Don't know
Hands	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Eyes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thyroid	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Gonads	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Skin	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Bone marrow	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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